GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[X] ORIGINAL [ ] REVISION NO. ______

Project No. E-24-621 (R5889-0A0) GTRI/~~GIT~~ DATE 1 / 31/ 85

Project Director: Gerald J. Thuesen School/~~Lab~~ ISyE

Sponsor: National Science Foundation

Type Agreement: Grant #MEA-8501237

Award Period: From 1/1/85 To 12/31/85 (Performance) 3/31/86 (Reports)

Sponsor Amount:

	This Change	Total to Date
Estimated:	$	$ 15,696
Funded:	$	$ 15,696

Cost Sharing Amount: $ 784 Cost Sharing No: E-24-321 (F5889-0A0)

Title: Planning Conference for Developing a Research Framework for Engineering Economics

ADMINISTRATIVE DATA

OCA Contact John B. Schonk x4820

1) Sponsor Technical Contact:

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Defense Priority Rating: N/A

Military Security Classification: N/A
(or) Company/Industrial Proprietary: N/A

RESTRICTIONS

See Attached NSF Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with GIT

COMMENTS:

Funds may not be expended past performance end date

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FORM OCA 4:383

GEORGIA INSTITUTE OF TECHNOLOGY **OFFICE OF CONTRACT ADMINISTRATION**

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 5/14/86

Project No. E-24-621 School/~~XXX~~ ISYE

Includes Subproject No.(s) N/A

Project Director(s) G. J. Thuesen GTRI/~~XXX~~

Sponsor National Science Foundation

Title-Planning Conference for Developing a Research Framework for Engineering Economics

Effective Completion Date: 12/31/85 (Performance) 3/31/86 (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [ ] Final Invoice or Final Fiscal Report
- [ ] Closing Documents
- [XX] Final Report of Inventions Questionnaire sent to P.I.
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other

Continues Project No.

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R. Embry

Form OCA 58:1004

APPENDIX VII

NATIONAL SCIENCE FOUNDATION Washington, D.C. 20550	FINAL PROJECT REPORT NSF FORM 98A	
PLEASE READ INSTRUCTIONS ON REVERSE BEFORE COMPLETING		
PART I—PROJECT IDENTIFICATION INFORMATION		
1. Institution and Address Georgia Tech Research Corporation Atlanta, GA 30332	2. NSF Program Production Research 4. Award Period From 1/1/85 To 12/31/85	3. NSF Award Number Grant #MEA-8501237 5. Cumulative Award Amount $15,696
6. Project Title Planning Conference for Developing a Research Framework for Engineering Economics		
PART II—SUMMARY OF COMPLETED PROJECT *(FOR PUBLIC USE)*		

This project develops a framework for considering future research efforts in the field of engineering economics. The framework consists of defining the general framework of the field by its fundamental principles, methodologies and applications. The specific elements associated with each of these three categories have been identified and listed.

To understand the relationship of engineering economics to other disciplines the interfaces between engineering economics and other knowledge bases are presented. In addition, the degree of utilization of engineering economics in other academic curricula are shown along with the degree of utilization by firms engaged in production.

Three different taxonomies have been developed for classifying various elements of engineering economics in a systematic format. These taxonomies provide a means for relating future research activities to a variety of frameworks for viewing the field. Some examples of applying these classification schemes to a few proposed research projects are included in this report.

Finally, a current glossary of terms used in engineering economics is included. This glossary is provided to enable those not familiar with the field to have a better understanding of its scope and thrust.

PART III—TECHNICAL INFORMATION *(FOR PROGRAM MANAGEMENT USES)*

1. ITEM *(Check appropriate blocks)*	NONE	ATTACHED	PREVIOUSLY FURNISHED	TO BE FURNISHED SEPARATELY TO PROGRAM: Check (√)	Approx. Date
a. Abstracts of Theses					
b. Publication Citations					
c. Data on Scientific Collaborators					
d. Information on Inventions					
e. Technical Description of Project and Results					
f. Other *(specify)*					

2. Principal Investigator/Project Director Name *(Typed)*	3. Principal Investigator/Project Director Signature	4. Date
Gerald J. Thuesen		4/16/86

NSF Form 98A (3-83) Supersedes All Previous Editions — Form Approved OMB No. 3145-0058

INSTRUCTIONS FOR FINAL PROJECT REPORT
(NSF FORM 98A)

This report is due within 90 days after the expiration of the award. It should be submitted in two copies to:

National Science Foundation
Division of Grants and Contracts
Award Accountability Branch
1800 G Street, N.W.
Washington, D.C. 20550

INSTRUCTIONS FOR PART I

These identifying data items should be the same as on the award documents.

INSTRUCTIONS FOR PART II

The summary (about 200 words) must be self-contained and intelligible to a scientifically literate reader. Without restating the project title, it should begin with a topic sentence stating the project's major thesis. The summary should include, if pertinent to the project being described, the following items:

- The primary objectives and scope of the project.
- The techniques or approaches used only to the degree necessary for comprehension.
- The findings and implications stated as concisely and informatively as possible.

NSF may disseminate the project report through the National Technical Information Service (NTIS) of the Department of Commerce. Authors should also be aware that the summary may be used to answer inquiries by nonscientists as to the nature and significance of the research. Scientific jargon and abbreviations should be avoided.

INSTRUCTIONS FOR PART III

Items in Part III may, but need not, be submitted with this Final Project Report. Place a check mark in the appropriate block next to each item to indicate the status of your submission.

a. Self-explanatory.
b. For publications (published and planned) include title, journal or other reference, date, and authors. Provide two copies of any reprints as they become available.
c. Scientific Collaborators: provide a list of co-investigators, research assistants and others associated with the project. Include title or status, e.g. associate professor, graduate student, etc.
d. Briefly describe any inventions which resulted from the project and the status of pending patent applications, if any.
e. Provide a technical summary of the activities and results. The information supplied in proposals for further support, updated as necessary, may be used to fulfill this requirement.
f. Include any additional material, either specifically required in the award instrument (e.g. special technical reports or products such as films, books, studies) or which you consider would be useful to the Foundation.

SCHOOL OF INDUSTRIAL AND SYSTEMS ENGINEERING

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

RESEARCH PLANNING CONFERENCE FOR DEVELOPING A RESEARCH FRAMEWORK FOR ENGINEERING ECONOMICS

EDITOR

Gerald J. Thuesen

Sponsored by the

National Science Foundation
Grant No. MEA-8501237
March 25, 1986

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FORWARD

Introduction

The field of engineering economics has been evolving over the last 100 years as a body of knowledge essential to the process of economic decision making. As the complexity of these type of decisions increased and the competition in world markets stiffened, the greater the need for approaches to assist those responsible for making such decisions. To satisfy these increased demands the body of knowledge known as engineering economics had to be expanded.

This expansion of knowledge needed to be directed so that the new challenges facing our economy could be addressed. These challenges that include new manufacturing technologies, computer-aided design, and artificial intelligence are rapidly changing and there is little understanding of their contributions to the economic well being of the firm.

To assess these contributions new approaches and techniques must be developed for the field of engineering economics. Thus, at this time in history significant improvements in the field are being demanded. One response to these demands is to expand the research efforts in engineering economics and to focus on the problems of greatest concern. This realization that new research initiatives would be required began a series of important events that eventually led to the effort represented through the completion of this report. To better understand the context in which this project was undertaken, the sequence of the most recent of these events is reviewed.

In early 1983 Dr. W. J. Fabrycky and Dr. William Spurgeon began discussion at the National Science Foundation (NSF) regarding the need to develop a research agenda for engineering economics. In June 1983, Dr. G. J. Thuesen, proposed a symposium to allow those active in engineering economics research the opportunity to meet and discuss their current research interests. This meeting (the American Society of Engineering Education sponsored Economic Decision Analysis Research Symposium) was held May 5 and 6, 1984, and attended by 15 members of the academic community representing universities across the United States. In addition, to the discussion of current research, this group participated in developing the objectives and format for a NSF sponsored conference.

Dr. Fabrycky organized this conference with NSF support and it occurred on August 26-29, 1984 at Mountain Lake, Virginia. The conference officially known as the NSF Research Planning Conference on Engineering Economics was attended by twenty-two academicians and nine non-academic participants. A primary objective of this conference was the identification of important future research projects and the prioritizing of these projects. (For a summary of the planning process and the resulting ranking of potential research projects at the Mountain Lake Conference see Appendix A).

Following the highly successful Mt. Lake conference a proposal was presented by Dr. G. J. Thuesen to the National Science Foundation during September 1984. This proposal was for a Planning Conference for Developing a Research Framework for Engineering Economics. The proposal was funded in January, 1985 for the year of 1985. This report is the result of the NSF funding of Grant No. MEA - 8501237.

Purpose

The purpose of the grant was to assemble six experts in the field of engineering economics to develop a rational framework for future research. This purpose is accomplished by completing a number of tasks. These tasks include the definition of the scope of the discipline and a statement of the important interfaces with other disciplines. Additional tasks included the development of taxonomies to facilitate an understanding of the field and the compilation of a glossary of standard terms and definitions.

Participants

There were seven active participants in the Planning Conference for Developing a Research Framework for Engineering Economics. The task-force consisted of three members from industry, three members from academia and one member representing the National Science Foundation, the sponsoring agency. The individuals and their affiliation at the time of their participation are listed on the following page.

PLANNING CONFERENCE FOR DEVELOPING A RESEARCH
FRAMEWORK FOR ENGINEERING ECONOMICS

Conference Participants

Current Affiliation	Affiliation During Conference
James A. Bontadelli Tennessee Valley Authority 100 Hamilton Banks Annex Knoxville, Tennessee 37922 (615) 632-6660	
Michael C. Burstein Industrial Technology Institute Center for Social and Economic Issues P.O. Box 1485 Ann Arbor, MI 48106 (313) 665-4168	Department of Industrial Engineering and Operations Research University of Massachusetts Amherst, Massachusetts 01003
Wolter J. Fabrycky Department of Industrial Engineering and Operations Research VPI and State University Blacksburg, Virginia 24061 (703) 367-2782	
Richard A. Leshuk Federal Systems Division - IBM 9500 Godwin Drive Manassas, Virginia 22110 (703) 367-2782	
Grady E. Means Coopers and Lybrand 1800 M. Street, N.W. Washington, D.C. 20036 (202) 822-5520	
William M. Spurgeon Manufacturing Engineering The University of Michigan-Dearborn Dearborn, MI 48128	Manufacturing Systems National Science Foundation 1800 G. Street N.W. Washington, D.C. 20550 (202) 357-7676
Gerald J. Thuesen School of Industrial and Systems Engineering georgia Institute of Technology Atlanta, Georgia 30332 (404) 894-2314	

Conference Activities

The activities of the planning conference were centered around two meeeetings held in the Spring of 1985. The first meeting occurred on March 28 and 29th and was held in the School of Industrial and Systems Engineering at Georgia Tech in Atlanta, Georgia. All seven members of the task force attended this two day meeting. (The agenda for this meeting is presented in Appendix B, pp. B1, B2).

To assure that substantive progress would be made during this initial meeting each member of the task force was given pre-meeting assignments. These assignments are shown on page B3 of Appendix B. (The enclosures sent to each participant and referenced in the list of pre-meeting assignments are not included here because of the large number of pages involved.) Because each of the participants had made a substantial effort to complete these assignments, much time was saved in getting the task force "up to speed" regarding the tasks at hand. By scheduling the individual presentations at the beginning of the first day most of the preliminary ideas were "on the table" by the middle of the day. Detailed discussions by sub groups assigned to specific topics allowed for refinements to these ideas. The ideas with their refinements were then presented to the entire group which then attempted to organize them into a logical framework. Within the two-day meeting time great progress had been realized.

To enable the task for to digest the developments of March 28 and 29th it was decided that we wait a month before reconvening. Again the participants were assigned new tasks so that they would be prepared for the two-day meeting held on May 4th and 5th of 1985. This meeting was held in the offices of the National Science Foundation in Washington D.C.

The pre-meeting assignments are presented on pages B4, B5, and B6 of Appendix B. The agenda for the May meeting, shown on pages B7 and B8 of Appendix B, was based on the progress achieved by the task force during April. To organize the results of the task force's activities an outline of conference results was prepared by G. J. Thuesen. (See page B9, Appendix B) This framework for the final report was presented at the beginning of the two-day meeting in May and it focused the task force's efforts on finalizing and organizing the concepts and ideas that had been developed.

In June 1985, preliminary results were sent to the participants for review. Additional responses were received during the summer. Writing of the final report began in November of 1985 and by February 1986 a preliminary version of this report was sent to all participants. Their responses and suggestions were then incorporated into the final report.

I. OVERVIEW OF THE FIELD OF ENGINEERING ECONOMICS

1.1. Definition Of Engineering Economics

The terms "engineering economy" and "engineering economics" are used interchangably to describe a body of knowledge concerned with the economic evaluation of capital investment decisions. The techniques of this discipline have found widespread application in industry and government. Engineering schools and colleges have included engineering economics as a basic element required in most engineering curricula.

The book considered to be the forerunner of field, "The Economic Theory of Railway Location," was written by Arthur M. Wellington and published in 1877. With an early focus on the need to assess the economic feasibility of civil engineering projects the field has continued to develop and broaden in scope. The generality of the techniques of engineering economics has resulted in their use by not only those in engineering but by those involved with financial decisions of the firm. Therefore engineering economics has been thrust into the domain of corporate finance, strategic planning, capital budgeting and other areas of economic decision-making.

To better understand the scope and thrust of the discipline of engineering economics, a set of definitions are presented. The first set of definitions represent those used in the early 1970's as a part of the American National Standard Institute's (ANSI) standards on terminology and notation. The Z94.5 standard for Engineering Economy presents the following definitions of Engineering Economics.

(1) The application of engineering or mathematical analysis and synthesis to economic decisions.

(2) A body of knowledge and techniques concerned with evaluation of the worth of commodities and services relative to their cost.

(3) The economic analysis of engineering alternatives.

One of the tasks for the NSF Planning Conference on a Framework for Research in Engineering Economics was the development of a definition for the field. A new definition suggested by the task force better represents the future direction of the field when contrasted with the definitions previously presented.

> Engineering economics is concerned with the definition and life-cycle evaluation of technical alternatives in terms of worth and cost. It embraces the fundamental concepts of structuring alternatives, estimating economic elements, developing cash flows, defining criteria for comparison, optimizing decisions and auditing the implementation of those decisions.

This definition attempts to be more specific by recognizing the breadth and diversity of the field. The use of the term "life-cycle" indicates that the methods and the techniques of engineering economics are applicable to the wide range of activities required in the process of bringing a product or service into existence. These activities comprise both the acquisition phase and the operation phase of the product life-cycle. The activities begin with the "needs assessment" and extend to the final activity of "disposal".

The definition also indicates the range of fundamental elements that comprise the technical basis of the field. Thus, the definition presents a description of the range of the field's applications along with the range of its technical elements. This scheme of classification is utilized throughout this report. It represents a more precise and systematic description which facilitates a better understanding of the field of engineering economics.

1.2. General Framework Of Engineering Economics

Given the definition of engineering economics as just presented, a more specific and detailed description is provided to present the field in its totality. First, a general framework is defined, followed by the classification of specific elements and activities within this framework. The initial task in describing the framework of engineering economics is the identification of the fundamental principles that are the foundation of the field.

There are a number of basic concepts that constitute the fundamental principles of the field of engineering economics. These fundamentals which are, axiomatic or theoretically based, form the core ideas that tie the body of knowledge of the discipline to a solid foundation. Although these principles are not unique to engineering economics it is the grouping of, and emphasis given those principles that engenders the special character of this discipline.

Because these fundamentals are timeless and therefore unchanging, engineering economics has provided concepts and methodologies on which the user could rely. For almost 100 years the body of knowledge has continued to expand and evolve. The result is a highly dependable set of techniques and methodologies that have been time tested. When this dependability is coupled with the relative simplicity of application, the usefulness and power of the discipline becomes evident.

As a consequence, the body of knowledge classified as engineering economics is widely recognized as an important element in the academic curriculum. It is taught in most engineering and engineering technology programs. In addition, many of the same or related methodologies are now found in financial management curricula. Thus, academia has judged both the fundamentals and the applicability of the methodologies to be sound and utilitarian.

The users of these methodologies outside academia have also judged them favorably as evidenced by their pervasiveness throughout industry and government. The continued use of these methods has reaffirmed their legitimacy and developed a confidence in their use.

The following section presents a list of the fundamental concepts of engineering economics. A short explanation of each concept is presented.

1.2.1. Fundamental Principles

The principles listed below are quite general and inclusive and they provide a basis for the body of knowledge known as engineering economics. These principles are relevant for a wide range of decision problems including both strategic and tactical decisions.

These principles have their basis in the fundamental concepts of mathematics and economics. However, they also possess great utility in that they provide a mind-set for the user which enhances his ability to function properly in the application of the methodologies.

[1] Choice is among alternatives

Only when confronted by more than one course of action is it necessary to make decision or choices. The identification and delineation of alternatives is essential and critical to the assessment of decision options. The quality of the outcome pursued is inextricably tied to the options considered.

[2] The full life-cycle of an alternative must be considered

When describing alternative courses of action, it is critical that the consequences of an alternative include <u>all</u> the effects of the alternative. By defining an investment's life-cycle as the time from inception to the end of its existence, the full range of the consequences are considered over time.

[3] Economic alternatives are described by their cash flows.

The perspective assumed is that the exchange of money associated with an alternative completely describes the economic worth of the alternative. It is the magnitude and timing of the receipts and disbursements that defines the economic characteristics of an alternative.

[4] Money has a time value

The recognition of both the earning power of money and the purchasing power of money is essential to the proper evaluation of economic worth of an alternative. Both of these effects have real economic impact and they are based in compound interest economics.

[5] Equivalence between cash flows can be calculated

It is possible to calculate different sequences of cash flows with regard to their timing and magnitude for which there is preferential indifference. The interest formula of engineering economics define this relationship.

[6] Worth of an economic alternative is measurable in quantitative terms

By the proper mathematical combination of elements different insights are provided regarding the estimated future consequences of a decision option. The variety of objectives pursued by industry and government provides innumerable opportunities to structure new and useful quantitative measures of both economic and non-economic worth. The acceptance of these measures usually depends on the quality of the insight provided and/or the type of application considering the available data.

[7] The choice between alternatives is based on the differences between them.

The concept of marginal analysis pervades the fields of economics and decision analysis. It reflects the axiom that choices are made between alternatives on the basis of those characteristics that create the differences between them.

[8] Decision rules are required for the comparison and selection of alternatives

The decision rule must be compatible with the objective to be realized in the economic comparison of alternatives. For some objectives no decision rules exist while for others a variety of rules will accomplish the same objective.

[9] Optimization of economic worth is one objective in the evaluation of economic alternatives

The concept of optimization is a basic economic idea. The attempt to utilize resources in the <u>most</u> efficient manner is a common objective sought in the economic environment. Even though it is usually recognized that this ultimate objective may not always be attainable, many rules of choice are designed to achieve this ultimate level of efficiency.

[10] The utility of an outcome or an object is determined by the preference that an individual or organization has for these items

The concept of utility allows for the recognition and measurement of preferences regarding the economic and non-economic features of decision options. The explicit understanding of the utility associated with these options provides the basis for rational choice.

[11] Risk is the exposure to undesirable consequences.

The existence of some probable economic loss or ruin associated with many decision options requires explicit recognition of this important consideration. This danger must be an integral part of any theory dealing with the problems of economic choice.

[12] Uncertainty represents the fact that the outcomes of future events are not known with precision.

There are many factors and forces at work in the economic environment that affect events in such a manner that exact prediction of their outcomes is impossible. Probability theory has provided the framework for the quantitative representation of uncertainty.

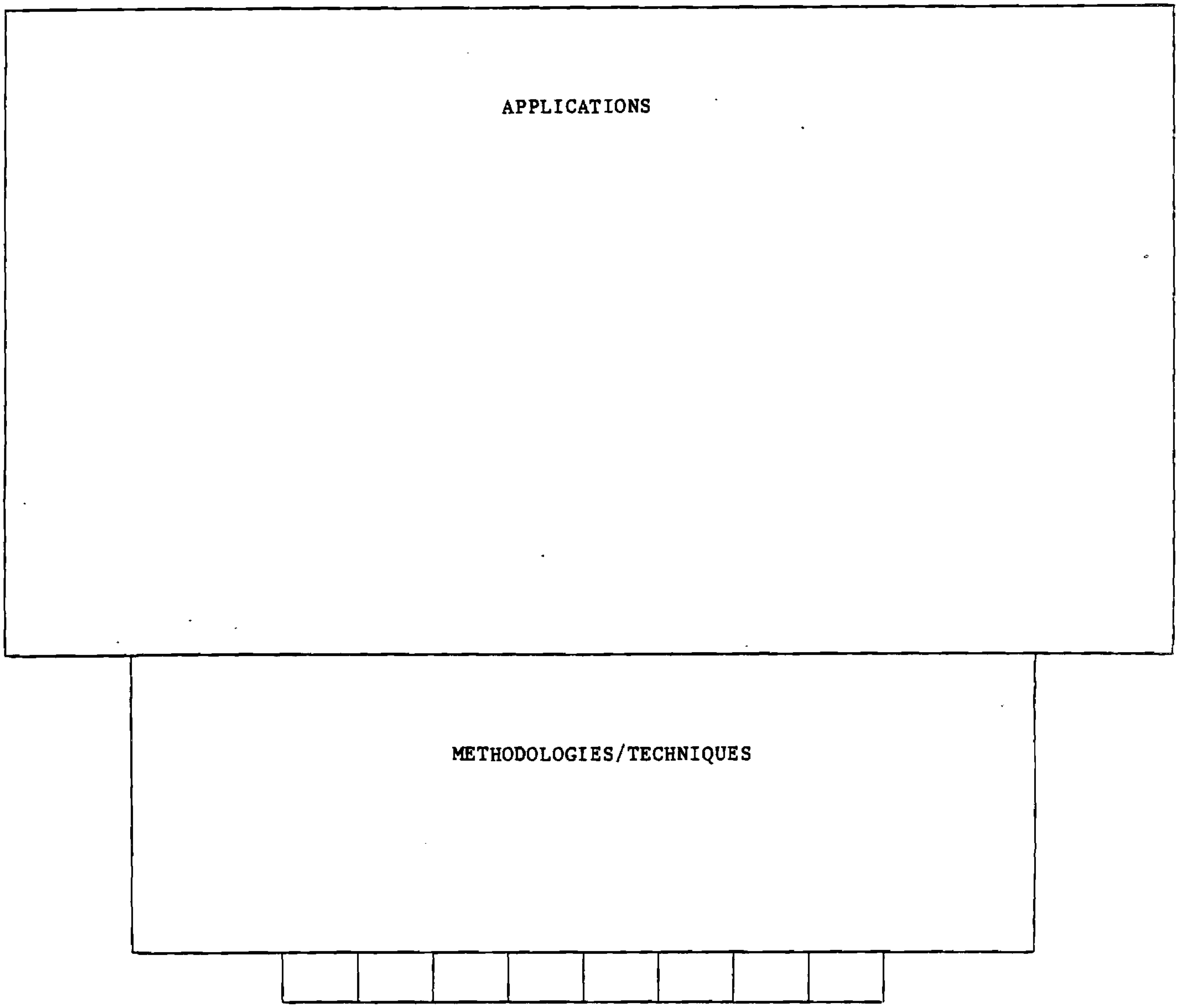
1.2.2. Methodologies/Techniques

The basic principles just presented provide the foundation for a highly diverse but highly utilitarian set of methodologies and techniques that form the technical content of the discipline. This technology is quantitative and logic based while encompassing the variety of economic concepts and phenomena experienced in the world of practical decision-making. Figure 1 indicates that a much larger set of methodologies/techniques are derived from the fundamental concepts of the field.

The technical content of the discipline has a distinct science base with much of the new technology resulting from both academic and industrial research. A portion of the technology has evolved from the experience developed when confronting economic choices in the competitive world of free enterprise.

BODY OF KNOWLEDGE

ENGINEERING ECONOMICS



FUNDAMENTAL CONCEPTS

Figure 1. Three basis categories of engineering economics representing the body of knowledge of the field.

1.2.3. Applications

Because the major portion of decision problems have a basic similarity for almost all forms of industry and government, the power of engineering economics resides in its general applicability. Firms or government agencies have alternatives which they desired to assess in terms of their objectives and these objectives are stated in economic forms. As a result of this commonality of need and objective, the number of applications of engineering economic technology is enormous. In Figure 1, the set of applications which utilize the technology of the discipline is depicted as many times larger than the tools of the field.

The applications of this field exceed the technology utilized to a far greater extent than that realized in most other fields of engineering and science. Therein lies the importance of research in the area of the methodologies and techniques of the field. The impact of a relatively small number of improvements in the technology can be enormous because of the large number of applications that might be affected.

1.3. Specific Elements of the Engineering Economics Framework

To be more specific regarding the three classifications depicted in Figure 1, a list of elements belonging to each classification is provided. This list is published by The Engineering Economist, the technical journal of the engineering economy profession, to inform their readers of the areas of interest covered by this journal. These areas are not all inclusive but they represent those activities seen to be of primary interest to the profession. The breadth and diversity of engineering economics is manifest by this listing.

1.3.1. Fundamental Principles

The twelve elements comprising the fundamental concepts previously described in this section are listed first.

[1] CHOICE AMONG ALTERNATIVES

[2] LIFE-CYCLE PERSPECTIVE

[3] CASH FLOWS

[4] TIME VALUE OF MONEY

[5] EQUIVALENCE

[6] ECONOMIC WORTH

[7] MARGINAL COMPARISON

[8] DECISION RULES

[9] EFFICIENT USE OF CAPITAL

[10] UTILITY

[11] RISK

[12] UNCERTAINTY

1.3.2. Methodologies/Techniques

The methods and techniques of engineering economics provide the rational and systematic basis for analysis that characterizes the discipline. These techniques, which are primarily based in mathematics, deal with all forms and elements of economic decision problems. The following listing of these techniques and methods, although not all inclusive, gives some indication of the diversity of analytical tools available.

ACCOUNTING
BENEFIT COST ANALYSIS
BREAK-EVEN ANALYSIS
CAPITAL BUDGETING
CAPITAL INVESTMENT ANALYSIS
CASH FLOW ESTIMATING
COMPUTERIZED METHODS
COST ACCOUNTING
COST ANALYSIS
COST EFFECTIVENESS
COST ESTIMATING
COST OF CAPITAL
DECISION ANALYSIS
DECISION CRITERIA
DECISION THEORY
DEPRECIATION AND OBSOLESCENCE
ECONOMIC COMPARISONS
ECONOMIC VALUATION
FINANCE
FORECASTING
INFLATION EFFECTS
INTEREST RATES
MANAGERIAL ECONOMICS
MATHEMATICAL PROGRAMMING
MEASURES OF WORTH
MULTIPLE CRITERIA ANALYSIS
PARAMETRIC ESTIMATING
PRIORITY ANALYSIS
PROBABILITY THEORY
PRODUCTION ECONOMICS
PROPERTY MORTALITY CURVES
RESOURCE ALLOCATION
REVENUE REQUIREMENTS
SENSITIVITY ANALYSIS
SIMULATION
STUDY PERIOD
TAXATION
UTILITY THEORY

1.3.3. Applications

Almost any sector of the economy can make effective use of the principles and methodologies/techniques that comprise the field of engineering economics. Any form of endeavor that requires the consideration of economic decision options is a candidate for the application of this field of knowledge. Following is a partial list of applications that reflects the primary interest of those practioners of engineering economics. This list indicates those areas of traditional and current interest of the members of the profession. (These applications are the list that The Engineering Economist has indicated as areas of primary interest).

ABANDONMENT
ACQUISITION
ADMINISTRATION
BIDDING
BUDGETING
CAPACITY EXPANSION
CASE STUDIES
COMPUTER AIDED DESIGN
COMPUTER CODES
CONSTRUCTION
CORPORATE DECISIONS
COST CONTROL
COST ENGINEERING
DECISION SUPPORT
DESIGN
DIVESTMENT
ECONOMIC DEVELOPMENT
EDUCATION
EDUCATIONAL METHODS
ENERGY
ENVIRONMENTAL STUDIES
FOREIGN INVESTMENT
GOVERNMENT
INDUSTRY
LEASING
MANUFACTURING
MERGER ANALYSIS
MILITARY
OPERATIONS
PLANNING
PLANT LOCATION
PLANT SIZING
POST AUDIT
PRICING
PRODUCTION
PROJECT CONTROL
PROJECT IMPLEMENTATION
PROJECT JUSTIFICATION
PUBLIC UTILITY
RECREATION
REPLACEMENT ANALYSIS
RESEARCH
SERVICE
SOCIAL CHOICE
TRANSPORTATION
VALUATION

It should be noted that at least three categories of applications are represented in the preceding list. First there are a number of applications that can be identified by the particular type of decision problem involved. (eg. Abandonment, Acquisition, Plant Sizing, Replacement Analysis, etc.) Second, there are applications that are associated with particular sectors of industry and government. (eg. Construction, Education, Manufacturing, Energy, Transportation, Military, Recreation, etc.) Third, there is a group of these applications, that can be characterized by the type of functional activity within an organization where the techniques of engineering economics are utilized. (eg. Cost Control, Design, Operations, Planning, Post Audit, etc.)

It is not the purpose of this list to provide an exhaustive view of all applications but to engender some perspective of the diversity of applications. Recognizing that engineering economic techniques and methods are currently being applied in each of these areas, the widespread reliance on the methods of the discipline becomes evident.

II. THE INTERFACES OF ENGINEERING ECONOMICS

A more complete understanding of engineering economics requires a knowledge of how the field relates to other academic disciplines and the functional needs of industry. In the following section three distinct perspectives are utilized to assist in identifying the boundaries of the discipline. First, the interfaces between engineering economics and other knowledge bases will be presented. Next, relationships between the field and other academic curricula are examined. Last, the relative importance of the field to various functional areas within firms engaged in production activities are presented.

2.1. Interfaces Between Engineering Economics and Other Knowledge Bases

Engineering economics finds its roots in the art and science of economic decision making to meet the needs of engineering. With an initial start in the economic theory of railway location, the field has grown over almost 100 years to a field of study with broad concerns about the problems of economic choice. During this growth, the field developed many new techniques which were adopted by other disciplines while simultaneously utilizing many new ideas and techniques developed elsewhere.

Because the problems of decision encompass such a variety of disciplines ranging from psychology to mathematics optimization, engineering economics has interfaced with a broad spectrum of disciplines. This interaction has expanded over time and the delineation of the specific contributions made to and received from other disciplines would be beyond the scope of this report. However, by selecting the nine most significant disciplines involved in the interface with engineering economics and presenting a graphical representation of the technical interfaces, the task becomes tractable.

The diagram in Figure 2 depicts these nine disciplines or knowledge bases as components ("slices") of the total knowledge base related to engineering economics. The circle represents the body of knowledge known as engineering economics. Each slice represents one of the nine knowledge bases that have important interfaces with engineering economics.

Within each slice are listed techniques, theory, and methods that are identified with that particular knowledge base. The elements listed <u>within</u> the circle intersecting the slices represent those items identified as part of enginering economics. Represented at the boundary of the circle are those elements of engineering economics that have their interface with the other elements of the knowledge bases. For example, the use and development of optimization techiques for replacement, multiple objective decision criteria, economic life, and etc. are based on the techniques of mathematical programming, and dynamic programming that constitute the knowledge base, optimization.

By examining Figure 2 one can observe the elements of engineering economics identified with its knowledge base (elements within the circle) and the interface between engineering economics and the broader knowledge base. This perspective confirms the breadth of knowledge on which the field of engineering economics has been fashioned.

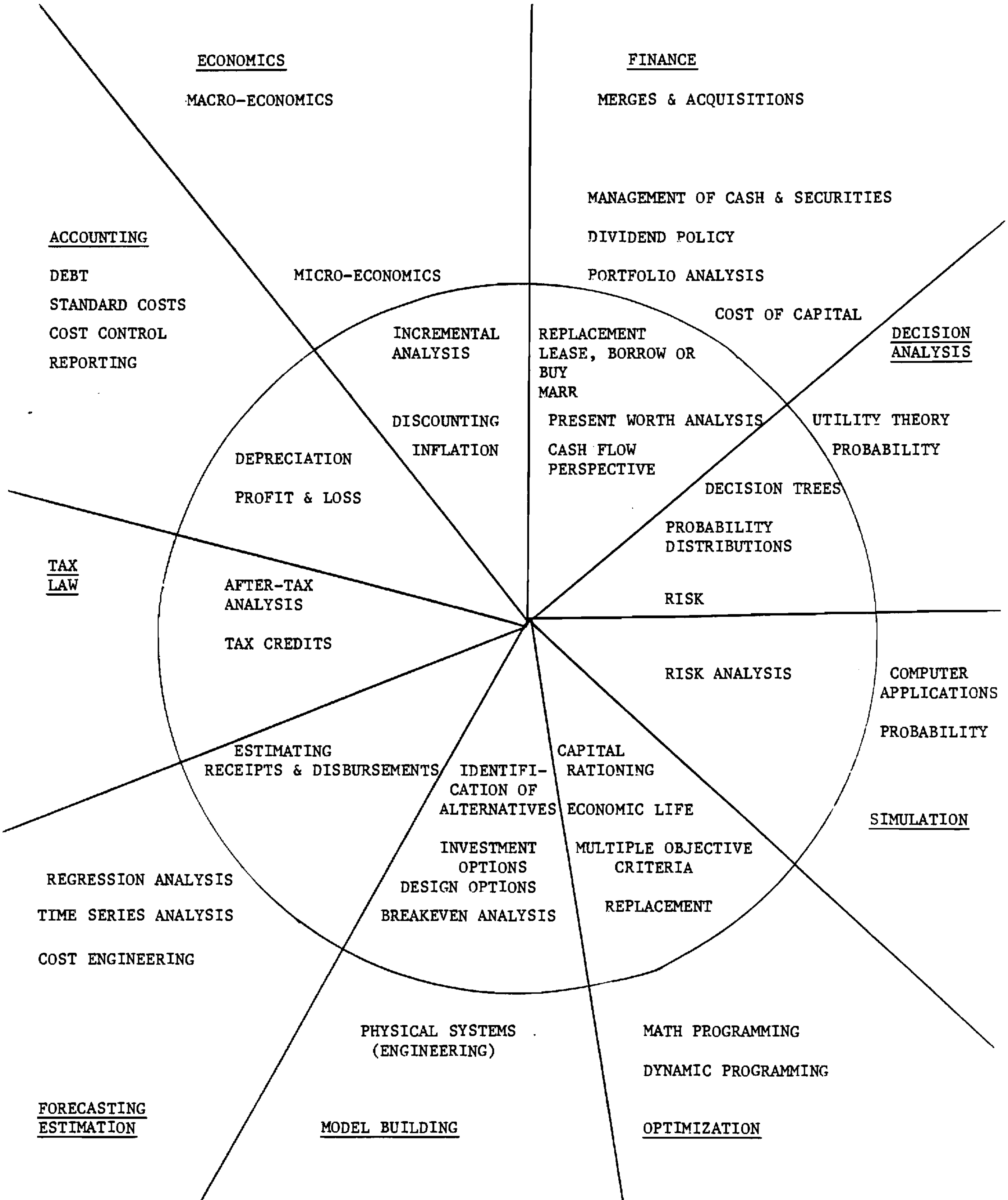
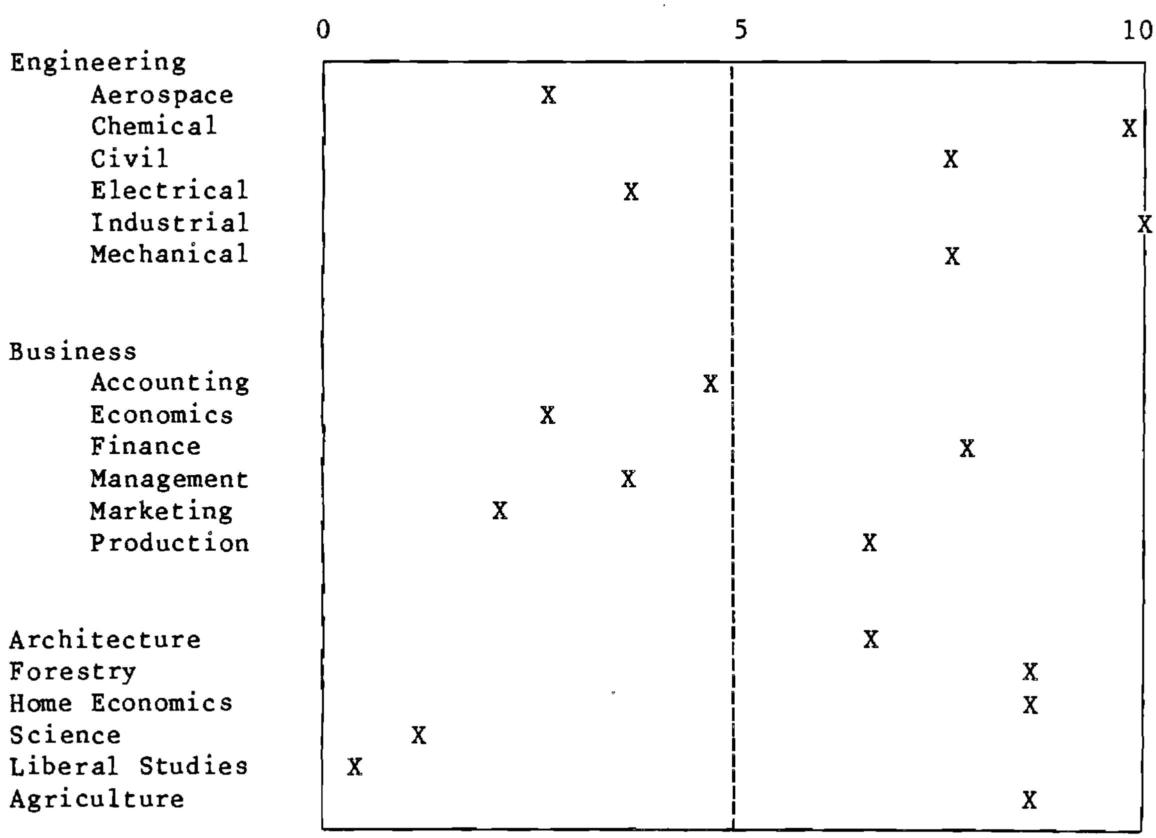


Figure 2. Technical Interfaces Between Engineering Economics and Other Fields

2.2. Interfaces Among Academic Curricula

Examining the relative importance of engineering economics as it relates to a number of academic curricula also provides an important perspective of the field. In Table 1 a number of academic disciplines are listed. For each discipline the degree of emphasis of engineering economics was assessed by the conference participants. A continuous

Table 1. Emphasis Given Engineering in Other Academic Fields



scale of 0 to 10 is used to present these assessments. The scale represents relative emphasis compared to the maximum utilization of engineering economics as it presently appears in academic curricula. Thus, Industrial Engineering which presently gives the greatest emphasis to the field is given the highest rating of 10. A score of zero indicates the total exclusion of the knowledge base from the academic discipline.

The scores presented in Table 1 represent the judgement of the participants and does not represent any quantitative analysis. The purpose being to indicate what academic disciplines have or have not chosen to include the study of engineering economics in their educational programs.

2.3. Degree of Utilization of Engineering Economics Within the Functions of a Firm Engaged in Production

Another important prospective regarding engineering economics is its application in industry. The setting used in this presentation is an industrial firm that is a producer of goods. Table 2 presents a listing of the various functions that would be found in such a firm.

Generally, economic decisions about operations and capital investment constitute a large proportion of all engineering analyses. Operating decisions are those choices that deal with the efficient production of goods with a given set of physical assets. Capital investment decisions represent the selection or replacement of existing assets with new assets.

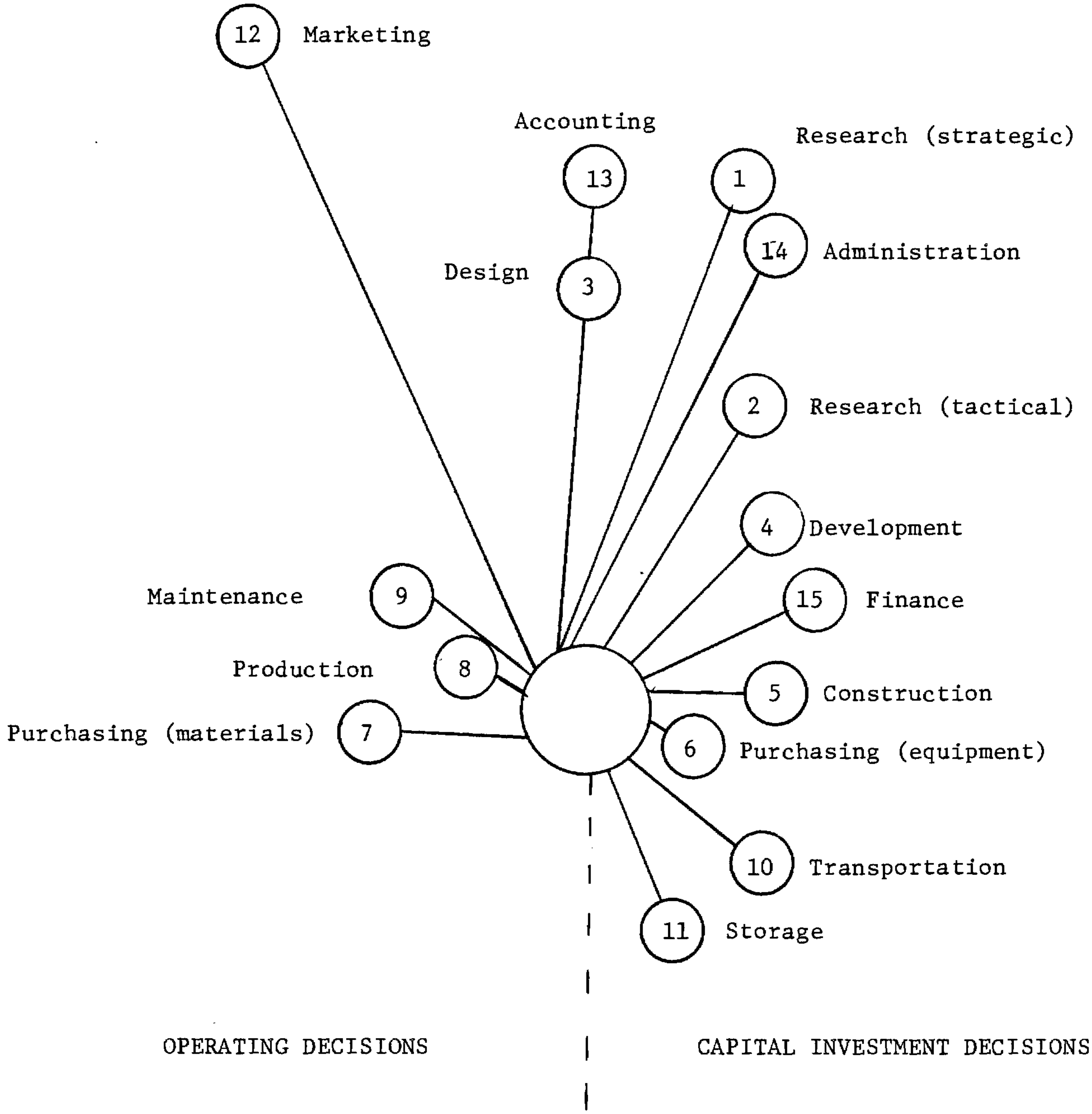
By estimating to what degree conventional engineering economics is utilized for these two categories of decisions for each of the functions listed in Table 2, additional insight is provided concerning the role of the field in industry. The numbers presented in Table 2 represent the degree of utilization based on a scale from 1 (low degree of use) to 10 (high degree of use).

Table 2. Degree of Utilization of Engineering Economics By the Functions of a Firm Engaged in Production

Decisions	Operating Decisions	Capital Investment
1. Research (Strategic)	2	4
2. Research (Tactical)	2	6
3. Design	3	3
4. Development	5	7
5. Construction	3	7
6. Purchasing (Equipment)	6	9
7. Purchasing (Materials)	6	2
8. Production	8	6
9. Maintenance	7	5
10. Transportation	4	7
11. Storage	4	7
12. Marketing	1	2
13. Accounting	2	2
14. Administration	3	4
15. Finance	2	7

Key: 1: Low Utilization
10: High Utilization

Figure 3 represents the information provided in Table 2 in a visual format. The relative importance of engineering economics regarding operating decisions is shown to the left of vertical while the relationships for capital investment decisions are shown to the right of vertical.



1. Distance from center represents the importance of engineering economics to the function (longer distance indicate lesser importance)

2. Deviation from vertical indicates if primary emphasis is on Investment Decisions (right of vertical) or Operating Decisions (left of vertical)

Figure 3. Degree of Utilization of Engineering Economics by Functions of a Firm Engaged in Production

The various functions are indicated by the circled numbers (nodes) that are identified in Table 2. The distance from the nodes to the center circle represents the relative importance of engineering economics in the performance of these functions. The closer to the center the greater its importance and the further from the center the less its importance. The striking fact displayed by Figure 3 is the variety of functions that rely to some extent on the techniques of engineering economics. In addition, the figure displays the potential for increased utilization in a wide range of functions. It is in these areas, where the additional research on the applications of engineering economics would provide potential benefits.

Those knowledgeable about the field of engineering economics generally believe that significant improvement in the performance of U.S. companies in world competition could be achieved through the increased utilization of techniques presently available. Thus, one of the important research tasks facing the profession is the investigation of the means for improving application in all of these functional areas.

III. TAXONOMIES FOR DESCRIBING ENGINEERING ECONOMICS

A primary task of the Planning Conference for Developing a Research Framework for Engineering Economics was the development of various taxonomies to characterize the field. The National Science Foundation grant that funded this effort intended that a variety of classification schemes be developed so that proposed research activities could be associated with the classes of activity identified as fundamental to engineering economics.

With this charge, the task force allocated a major portion of its effort to the development of three taxonomies. The first taxonomy developed is concerned with identifying the elements of engineering economics by the "tools" (methodologies/technologies) of the field and the position within a product's life-cycle where these tools are applied. This two dimensional classification scheme is the most general taxonomy developed by the task force.

The second taxonomy developed focuses on the more specialized application of engineering economics to financial systems for manufacturing. Because of the group's awareness of the great need for improvements in the area of manufacturing within the U.S., a major concern was understanding the role of engineering economics in this type of enterprise.

The third taxonomy produced by the task force deals with the understanding of the integration of engineering economics with the process of engineering design. The task force believes this area of activity holds great potential for the improvement of competitive position for products designed and produced in the U.S.

3.1. Taxonomy of Engineering Economic Methodologies and the Product Life-Cycle

3.1.1. General Description

The taxonomy for engineering economics detailed in this section presents the most comprehensive overview of the field. Figure 1 illustrated three classifications for describing the body of knowledge characterizing the field. These categories are:

1. Fundamental Concepts
2. Methodologies/Techniques
3. Applications

Because the research activities of the profession are primarily concerned with Methodologies/Techniques and Applications, it was decided that a two dimensional classification framework based on these categories would be most useful. The task was to identify the general elements describing the Methodologies/Techniques that constitute engineering economics. Six of the basic elements associated with the Methodologies/Techniques were identified and they are presented as row headings in Figure 4.

To develop a general overview of the components attendant with the applications of engineering economics to all endeavors, the life cycle view was adopted. This view, regarding the bringing <u>any</u> product into being, requires the consideration of the phases that constitutes the product's birth, life and death. The elements of the life-cycle description of these phases are the column headings presented in Figure 4.

The taxonomy presented in Figure 4 provides a basis for summarizing present and future directions of research in a comprehensive format.

LIFE-CYCLE / METHODOLOGIES/ TECHNIQUES	1. Need Determination	2. Concept Formulation/ Preliminary Design	3. Detail Design/ Development	4. Production/ Construction	5. Operational/ Support	6. Retirement/ Disposal
A. Definition of Alternatives						
B. Forecasting/ Estimating						
C. Cash Flow Development						
D. Analysis/ Evaluation						
E. Recommendation/ Decision						
F. Implementation/ Control						

Figure 4. Classification of Engineering Economics by Methodologies/Techniques and Life-Cycle

Additionally, this matrix framework can be utilized to classify other activities within the profession. For example this classification scheme could be utilized to analyze technical and professional publications, assess computer software, rate continuing education programs, and etc. Thus, the general applicability of this taxonomy along with its relative simplicity makes it a powerful tool for placing a variety of activities in proper perspective.

3.1.2. Row Definitions (Methodologies/Techniques)

The row elements of the taxonomy in Figure 4 are organized in the order usually followed when developing and evaluating an economic investment option. The series of logical steps begin with the Definition of Alternatives and end with the Implementation and Control essential to the success of any investment undertaking. The six essential elements are identified with letters A through F.

Those techniques utilized in the structuring of alternatives are classified with A while the techniques of cost estimating would be identified with B. Clearly certain row elements represent large groupings quantitative or "scientific" techniques (eg. Row D) while other elements represent methods and techniques developed through experience. Both types of techniques are legitimately represented by these lettered row headings.

The process of developing and evaluating an economic decision is observed as a series of logical steps. The following short descriptions of the row elements are presented to identify the methodologies/technique of engineer economics by the order in which they are commonly applied.

A. <u>Definition of Alternatives</u>: Structuring the technical alternatives requires a problem statement, definition of responsibility for the decision, and a thorough search for alternatives.

B. <u>Forecasting/Estimating</u>: Gathering and modification of data for assessment requires the estimation of the current and future cost of elements. Modelling, standard data, and history provide means for creating estimates.

C. <u>Cash Flow Development</u>: Definition of the profile of cash flows over the alternatives provides the basis for evaluation.

D. <u>Analysis/Evaluation</u>: Criteria for comparison and means of establishing economic equivalency must be defined in order to judge alternatives. The time value of money based on appropriately selected interest rates is the central concept. The cash flow analysis may be modified on the basis of "other" factors.

E. <u>Recommendation/Decision</u>: The output of the engineering economic evaluation is the economically optional solution from a group of competing technical alternatives. Effective communication of the essence of the economic assessment is critical.

F. <u>Implementation/Control</u>: Data collection and analysis permits the monitoring of progress, a basis for modification decisions, and a historical data base for future estimates.

3.1.3. Column Definitions (Life-Cycle Elements)

All products, systems, and structures come into being over time in accordance with a life-cycle which originates with the determination of a need and ends with phaseout and disposal. Successful engineering application depends upon life-cycle economic feasibility. Accordingly, the life-cycle was chosen as an organizing concept for focusing upon the appropriate application of the methodologies and techniques of engineering economics. Economic optimization over the life-cycle requires that the entire engineering profession embrace economic considerations at each phase.

The six elements represented by the matrix in Figure 4 are ordered according to the time sequence for their occurence. Need Determination (Column 1) represents the initial activity regarding a project's life-cycle while Retirement/Disposal (Column 6) would be the last activity ocurring in the life-cycle. The definitions for each of the column elements follow.

1. <u>Need Determination</u>: The want of people for the product, system, or structure arising from deficiencies or problems are delineated and specified.
2. <u>Conceptual/Preliminary Design</u>: Feasibility studies, advanced planning, design parameter determination, product support planning, and related macro-design activities.
3. <u>Detail Design/Development</u>: Design and development activities needed to specify and communicate the final

product design which includes prototyping, test evaluation, and production design.

4. Production/Construction: The activities of altering materials and combining components which results in the creation of the product, systems, or structure to include distribution/development.

5. Operation/Support: Product use and maintenance support after the product comes into being.

6. Retirement/Disposal: Product phase-out, material disposal, reclamation, and recycling.

3.1.4. Cell Definitions

To better assess the effectiveness of the taxonomy presented in Figure 4, the task force attempted where possible to summarize each of the cells in the matrix in terms of current engineering economics methodology, techniques and practice. The success of this process provided reinforcement for the task force regarding the usefulness of this taxonomy. The individual cell definitions that were prepared are presented in Appendix C. These definitions provide a more detailed description of the row and column elements and should be examined for additional insight regarding the life-cycle taxonomy.

3.2. Relationship between Engineering Economics and Financial Systems for Manufacturing

To better understand the role that engineering economics assumes in large U.S. manufacturing firms today, a framework is needed for classifying the critical elements of present-day financial systems. The diagram in Figure 5 is a schematic representation of the many diverse elements found in financial reporting systems. Activities ranging from Design and Engineering to Standards and Costs are represented here.

This framework presents a taxonomy that is useful for classifying where the current and future efforts in engineering economics are and should be directed. By understanding the goals of the manufacturing enterprise in the context of its financial systems, new ideas regarding the application of engineering economics and issues for further research can be related to these goals.

The problem faced by U.S. manufacturing companies today is that the market for most manufactured goods has become very price sensitive in the last couple of years and highly resistant to price increases. Manufacturers who traditionally obtained margin through price increases (especially during periods of strong economic recovery) have found the combination of low inflation rates and increased (low-cost/high-quality) imported foreign goods in the U.S. market has created price competitive circumstances for nearly every U.S. company, no matter how high-tech nor how large their traditional market share. This situation has forced companies to concentrate on strategies for cost control within the manufacturing process and this is where most companies feel their greatest potential for competitive edge will come.

Engineering economics, on the other hand, matured as a discipline during the period when corporations could increase price to achieve margin. In this case price essentially represented the sum of the costs plus appropriate profit margin. During the high inflation periods of the

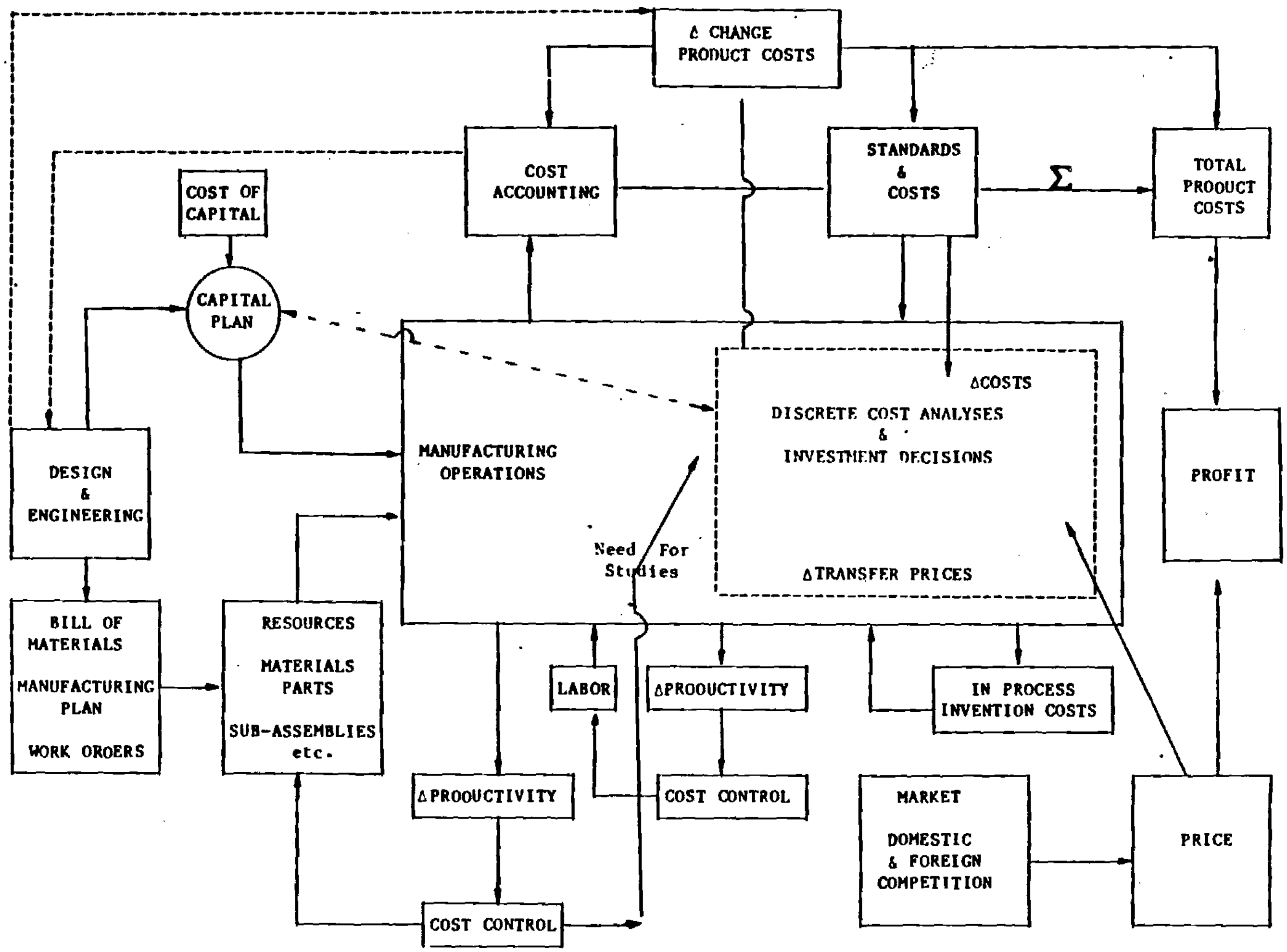


Figure 5. Interrelationships for Manufacturing Financial Systems

last 20 years, most companies developed strategies to increase prices with inflation during periods of economic recovery in the hopes of obtaining sufficient margin to ride out subsequent recessions. While cost control and productivity were occasionally topics of discussion, they were not areas of management consideration. In addition, engineering economics grew up in a period where real interest rates were relatively small (or even negative), and generally did not experience a great deal of variance. Therefore, engineering economics has traditionally associated cost with value and its techniques implicitly assume that price is set based upon costs. In addition, as the schematic in Figure 5 suggests, engineering economics also performs isolated analyses of the discrete parts of the manufacturing process, assuming that "value" in the process is associated with increased cost build-up and that a process pays for itself with a present value calculation based upon steady interest rates over the long term. Unfortunately, cost is no longer related to price; interest rates are not small nor steady, and therefore cannot hide mistakes; and with "real" interest rates, prices which build up in-process inventory create enormous carrying costs that may dramatically offset the increased efficiency of a new manufacturing approach in some discrete point in the manufacturing process.

In today's manufacturing environment, price equals price and is generally dictated to the company by the market, fully independent of cost. In order to calculate value in a manufacturing setting, value must be set equivalent to price minus costs; or, at discrete points in the manufacturing process, the marginal increase in the discrete transfer price minus a summation of cost at that point. The real cost of capital must be carefully understood, since it is variable and large. Banking deregulation, uncertainty in financial markets, and (perhaps) federal deficits, combined with low inflation rates, are creating conditions for a long-term sustained high real interest rate with a much higher year-to-year variance than every experienced in the past.

Manufacturers face several problems in this environment that engineering economics could address, although it does not do so.

- Manufacturers must better understand their performance. Engineering economics techniques can be useful for carefully analyzing the performance of various parts of the manufacturing process but they must perform such analyses with new techniques that appropriately take value and put it in the context of the entire manufacturing process rather than each isolated part. This is shown on Figure 5 as an additional output from all discrete economic analyses.
- Manufacturers also need better reporting and control systems. Current standard cost systems assume that cost relations on inputs to manufacturing are relatively constant one to the other. This no longer holds. They also do not anticipate bottlenecks and the consequences of inventory. Cost accounting and reporting systems do not provide very useful measures of cost performance to decision makers and the techiques of engineering economics might well be useful as a guide to the data collection and reporting approaches of cost accounting systems.

- An important factor in manufacturing analysis today is understanding the relative value of automated design and engineering systems (CAD/CAE/CAM). The only way to anlayze the value of these approaches is to determine whether they increase the total "value added" (value minus costs) for the entire manufacturing process. Do they improve the design, lower material usage, lower the scrappage rate, and allow the product to be manufactured in fewer and less time-consuming steps, <u>or</u> do they only accelerate certain parts of the manufacturing process, build up in-process inventory, and create new and unforeseen costs? Only techniques that can fully analyze the manufacturing process can answer these questions. Again, this is shown in Figure 5 as a feedback from the design and engineering activity where the estimated impact on product costs is an output from engineering economics analyses in the detail design. (See companion discussion in Section 3.3. Taxonomy of Engineering Economic Methodology and the Design Function).

Therefore, the above framework suggests a new, broader definition of engineering economics, a need for developing new analytic and, especially, <u>presentation</u> approaches for the science, and integrating it more completely into the problem-solving needs of manufacturers today.

3.3. Taxonomy of Engineering Economic Methodology and the Design Function

As shown in Figure 4, the matrix of Methodologies/Technologies versus Life-Cycle, two critical elements of the life-cycle are concerned with the design process. In addition, Figure 5, which deals with the manufacturing process, also indicates Design and Engineering as an essential element in the framework relating engineering economics to financial systems in manufacturing. Thus the design function that is exclusively the purview of engineering appears as a critical element in the two taxonomies previously presented. Because of the need for considering the economic impact of design decisions, the relationship of engineering economics to the design process is investigated in detail.

In an undated comment paper, Buck[1] summarized well the basic problem with the practice of engineering economics in the design and engineering activity:

> When engineering economics is a respected partner in the engineering family, this discipline will be a driving force rather than serving as an after-design test of acceptability. To be a driving force the discipline must serve the wants and needs of engineers of all disciplines in ways that the engineers could not do before.

In order to accomplish this, we need a significant improvement in our capability to apply present knowledge as well as to pursue a research program on methodology to develop better techniques and new knowledge. Technical integration of engineering economics into the design and engineering activity must be done primarily as part of the computer-aided

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[1] Buck, James R., "Engineering Economy for Engineering," an updated comment paper, University of Iowa.

processes which serve the engineer[2]. Interactive, real-time engineering economic analysis must become as natural to the engineer in the design process as the accomplishment of any of the other necessary steps in the process.

This integration of engineering economics with design activities has to be done within the context of a business as well as the more usual cash flow perspective, whether a new innovative product, structure, system or service is involved or the enhancement of an existing entity is the goal. It must be understood that design and engineering is the first step in meeting an economic need or want, whether being applied in the manufacturing, construction, or service delivery process.

In today's competitive market, price is primarily established by an international market, not by adding a profit margin to the costs of the company. Therefore, both the estimated marginal cash flow impact of alternatives and their contribution to cost changes and profit margin need to be known and sequentially refined in each phase of the design and engineering process.

3.3.1. Role and Use

The schematic in Figure 6 depicts the design and engineering activity from a macro interaction perspective of its major parts. Conceptual/Preliminary Design and Detailed Design are the two major divisions on the spectrum of design activity. Manufacturing engineering (or construction engineering) and industrial engineering knowledge are essential in each step of the design and engineering activity. The plan

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[2]The top priority research area identified during the NSF Research Planning Conference on Engineering Economics at Mountain Lake Virginia (August, 1984) was "The Economics of Design Trade-offs over the Life-Cycle" see Apepndix A (Table 2 and 3).

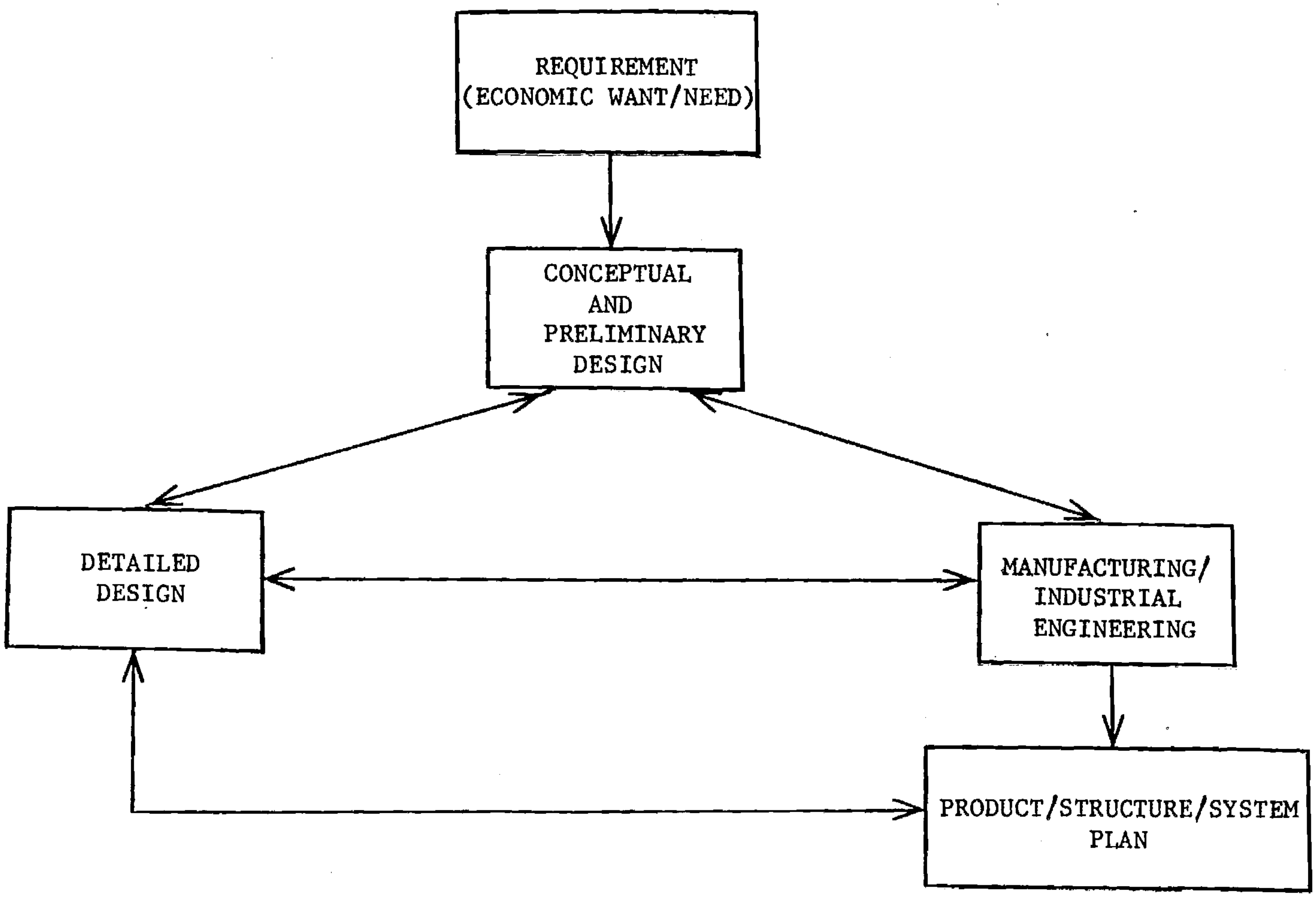

Figure 6. Engineering Economics and The Design Activity
(An Integrated Process Perspective)

for manufacturing the product, constructing the project, or developing the system must be "accounted for" in the detail design, and the plan integrates the design into the subsequent manufacturing or service delivery phases.

The role and use of engineering economics in the design and engineering activity are depicted in Table 3. The use of engineering economics for this activity is divided into three phases (preparatory steps, cost estimating, and analysis/use), and each of these phases is related to the two principal design phases.

In the preparatory steps (first phases), the engineering economics effort would develop a cost element structure for the particular design and engineering activity. Even though this is a primary concern, understanding the original requirement well and ensuring the development of an adequate work breakdown structure (WBS) for the total design effort are also essential for accomplishing the next two economic phases.

The cost estimating phase is described in the table by the type of estimate, level of "resolution," and methods for each of the two design phases. Preliminary cost estimate(s) are needed to support work during the conceptual/preliminary design phases. These estimates would be developed at a selected level of the WBS and for the major categories of the cost element structure. Then, the preliminary cost estimates would be successively detailed to explicitly reflect all levels of the WBS and all cost elements in the detailed design phase. The cost estimating methods range from the judgment, comparison, and macroparametric techniques for the preliminary cost estimate(s) to the detailed parametic, factor, bill of material extension, and standard time/cost techniques for the detailed cost estimate(s).

Table 3. Engineering Economics and The Design Activity
(Engineering Economics Role and Use)

Engineering Economics (Phase)	Design Phase (For Product/Structure/System)	
	Conceptual/Preliminary Design	Detailed Design
A. Preparatory Steps	1. Further delineate the requirement (economic want/need). 2. Develop initial structure of cost elements for life cycle. 3. Develop initial work breakdown structure (WBS).	1. Complete description of all cost elements. 2. Complete detailed development of WBS.
B. Cost Estimating:		
Type of Estimate	Preliminary cost estimate(s)	Detailed cost estimate(s)
Level of "Resolution"	1. Accomplished at selected level of the WBS. 2. For major cost areas. a. Design and engineering. b. Major hardware/structural components. c. Other material (direct, indirect). d. Labor (direct, indirect). e. Other costs. f. Overhead(s).	1. Accomplished in "build-up" sequence for <u>all</u> levels of WBS. 2. Includes all cost elements--not just estimates for the major cost areas.

Table 3. - Continued Engineering Economics and The Design Activity
(Engineering Economics Role and Use)

Engineering Economics (Phase)	Design Phase (For Product/Structure/System)	
	Conceptual/Preliminary Design	Detailed Design
Methods	1. Judgment (individual and peer group). 2. Comparison (with other known designs). 3. Unit method (per ft^2, per lb., etc.). 4. Macro-cost and time estimating relationships. 5. Design to costs.	1. Cost and time estimating relationships. 2. Bill of materials (takeoff and vendor quotes). 3. Standard time/costs. 4. Factor method.
C. Analysis/Use	1. Economic feasibility determination. 2. Analysis of basic concept design alternatives (to fulfill the requirement). 3. Marginal cash flow impact estimates. 4. Support general and technical management decisionmaking.	1. Analysis of detailed design alternative 2. Refined marginal cash flow estimates for alternatives. 3. Monitor estimated costs (and emphasize cost control in the design process). 4. Profit margin and price impact estimates. 5. Support technical management decisionmaking. 6. Add detailed cost estimate information to integrated data base--use in cost control during subsequent life cycle phases. 7. Make or buy decisions.

The third engineering economics phase (analysis/use) involves putting the results of the first two phases "to work" in real-time support of the design and engineering effort, and the related technical and general management decision making. During the conceptual/preliminary design phase, emphasis is on economic feasibility, analysis of the basic technical alternatives, and support of technical and general managment decision making. In the detailed design phase, emphasis is more at the technical detail level (e.g., numerous smaller design alternatives being analyzed versus the basic concept design alternatives)

3.3.2 Interactive Design and Engineering Economic Analysis Process

A general flowchart for a computer supported, interactive design and engineering economic analysis process is shown in Figure 7. The process described applies whether concept design alternatives are being developed and analyzed in the concept/preliminary design phase or detailed design alternatives are involved during the detail design/development phase. For the concept/preliminary design phase, the process begins with the economic want/need (or requirement) for an engineered product, structure, or system. For the detail design/development phase, the process begins with the preferred concept design alternative selected at the end of the previous phase.

As shown in the flowchart, four "key elements" must be brought together with interactive computer support provided before the design engineer can accomplish engineering economic analysis interactively as an integral part of the design process. These key elements are the work breakdown structure (WBS) description of the alternatives, a life cycle

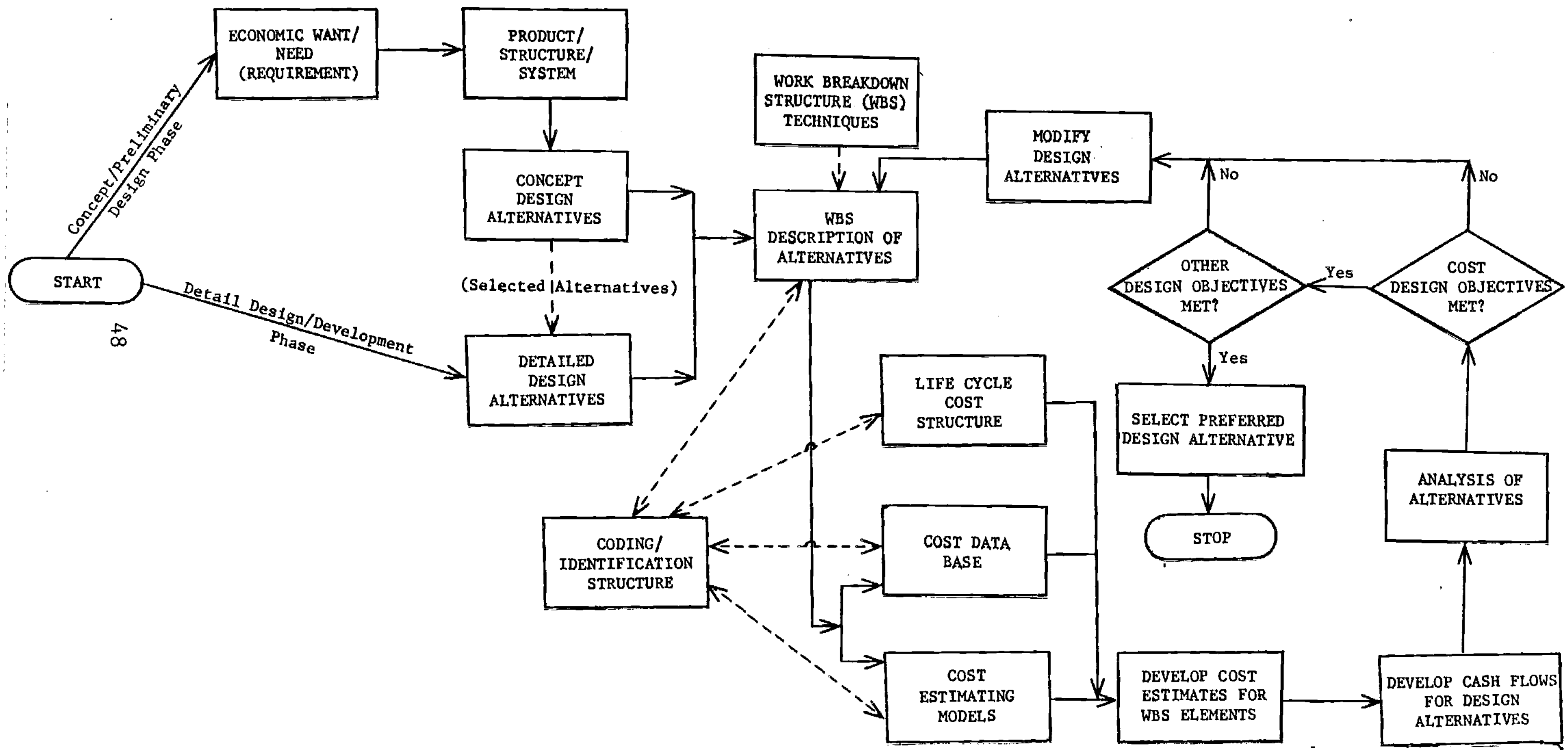

Figure 7. Interactive Design and Engineering Economic Analysis Process

cost structure, a cost data base (for the area of design involved), and the cost estimating models needed. The integration of these elements for use requires an adequate coding/identification structure. With these four elements integrated as described, and operationalized with the necessary data and interactive computer support, the engineer can repetitively: develop cost estimates for all elements in the WBS description of the alternatives (through a selected level), develop the cash flows for each design alternative, analyze the alternatives and determine whether or not the cost objectives have been met, and continue the design loop in the process until a preferred design alternative is selected.

3.3.3. Research and Development Needs

There are at least three basic areas that a research program on methodology in engineering economics, as related to the design and engineering activity, needs to pursue. The first is the methodology and integrating technique structures (and implementing software development) required so that it can become feasible for "the engineer" to accomplish engineering economic analyses repetitively during the design process. The second area is the various cost estimating techniques that will need to be integrated, and new techniques developed (particularly related to the area of computer-assisted design and manufacturing), to support the successive levels of design detail. The third area is developing the economic analysis output capability to include estimates on changes in product or service costs and profit margins, as well as the normal marginal cash flow analysis results.

Examining the research projects listed in Table 1 of Appendix A (the projects identified at the Research Planning Conference on Engineering Economics at Mountain Lake, Virginia), it is observed that a number of these projects deal with engineering economics in the design process. Listed below are specific projects that appear to be related to one or more of these three areas in engineering design.

1. Economic evaluation of design trade-offs over the life cycle (#26).

2. CAD-CAE, ocmputer-aided estimating (#10).

3. Parametric and shortcut estimating techniques (#12).

4. Model system performance--cost as impacted by design (#25).

5. Economic modeling of manufacturing processes (#30).

6. Economic modeling for production systems (#29).

7. Economic evaluation of software development for manufactuirng.

8. Develop method to integrate engineering economy with finance and accounting measures (#19).

9. Methodology for treating risk (#27).

IV. CLASSIFYING FUTURE RESEARCH IN ENGINEERING ECONOMICS BY PROPOSED TAXONOMIES

A primary purpose for developing the different classification schemes (taxonomies) presented in this report is to provide a framework for better understanding the scope of engineering economics and its relationship to other disciplines involved with economic decision-making. In addition, these taxonomies provide a systematic identification of the constituent elements of engineering economics. By relating present and future research projects to the appropriate elements, insight is obtained regarding the contribution of these projects to the overall improvement of the field.

Having already investigated the scope of engineering economics and its relationship to other fields in Sections 2.1, 2.2, 2.3, the following sections will explore the possibilities for considering research activities in the context of the taxonomies developed. First, the potential benefits of research to assist in the improvement of troubled sectors of the economy will be examined within the general framework of the field. Next, the results of the NSF supported Research Conference on Engineering Economics held at Mt. Lake, Virginia will be related to two different taxonomics. It is emphasized that the primary focus of the sections that follow is the presentation of the process to be utilized and the potential benefits from this process. The actual classification shown is only considered to be an example of how the taxonomics may be utilized.

4.1. Research Priorities Related to Fundamental Concepts

One approach to the classification of research would be to define particular research areas and to then categorize them according to the particular elements of the taxonomy being applied. For example, the task force identified some particularly troubled sectors of the U.S. economy as possible beneficiaries of new research efforts in engineering economics. Using the general framework of engineering economics presented in Section 1.1, judgements were rendered regarding the potential benefit that could be realized from additional engineering economics research. The results of these judgements are presented in Table 4. The numbered values indicate the potential benefit that might be realized on a scale from 0 (no benefit) to 10 (significant benefit).

Table 4. Potential Benefits of Research Classified by The General Framework of Engineering Economics

	Potential Benefit from Research		
Area of Need	Fundamental Concepts	Methodologies/ Technologies	Applications
Cost Overruns			
1. Construction	0	2	9
2. Design	0	4	9
3. Software	0	2	9
4. Flexible manufacturing systems	2	5	8
Government Policy Impact on Industries (Smelters, Foundries)	0	6	5
Firms That Have Failed (Home computers, robot manufacturers)	3	4	8
Troubled Businesses (Steel, shoes, T.V.)	2	5	8

It is observed in Table 4 that the task force believes that when considering government's impact on industries, future enginering economic research focused on fundamental concepts would be of no use in setting government policy. Research in improved techniques as opposed to research into new methods of applications is perceived to be slightly prefereed (6 compared to 5). However, since both scores are 5 or larger, this indicates that each of these research areas have important potential benefits.

The task force provides these values in Table 4 to demonstrate one method for classifying research areas. These values should not assume great significance but are presented primarily to described the use of one of the basic taxonomies developed during this project.

Another approach for the classification of research areas by fundamental concepts utilizes the future research areas as determined by the Mt. Lake, Virginia research planning conference. This conference, supported by the National Science Foundation, was called the Research Planning Conferences on Engineering Economics. The participants, including academic and industrial leaders in engineering economics, identified 33 research areas that were considered important both from an academic and industrial point of view. (A detailed summary of this conference is presented in Appendix A.).

To understand which of these research areas would benefit from future research directed at the fundamental concepts of engineering economics, specific research areas identified by number are classified in Table 5. For example, research areas (3) and (24) identified at the Mt.

Table 5. Classification of Research Projects by Fundamental Concepts

	FUNDAMENTAL CONCEPT	POTENTIAL	MT. LAKE PROJECTS
[1]	CHOICE AMONG ALTERNATIVES	Moderate	(3) (24)
[2]	LIFE-CYCLE PERSPECTIVE	Moderate	
[3]	CASH FLOWS	Low	
[4]	TIME VALUE OF MONEY	Low	
[5]	EQUIVALENCE	Low	
[6]	ECONOMIC WORTH	High	(19) (33) (20) (18)
[7]	MARGINAL COMPARISON	Low	
[8]	DECISION RULES	Moderate	
[9]	EFFICIENT USE OF CAPITAL	Moderate	
[10]	UTILITY	Moderate	
[11]	RISK	Moderate	
[12]	UNCERTAINTY	Moderate	

Lake conference, are considered to be primarily concerned with the problem of formulating alternatives. The research areas, their descriptions, and their number identifier are found in Table 1 of Appendix A. Therefore it would be expected that any new research findings regarding the statement of alternatives could be applicable to these two research areas. Other research areas from the Mt. Lake conference are associated with the other fundamental concepts in Table 5. Clearly, it is judged that few of the 33 projects resulting from the Mt. Lake conference are intended to deal with the fundamental principles of the field. Thus Table 5 provides a structure for making rational classifications of these widely diverse research areas.

Also, listed for each of the fundamental concepts is the task force's assessment of the potential benefits expected from additional research expressly directed at possible improvements in these concepts. A quick study of Table 5 reveals that the task-force judges only one of the fundamental areas, Economic Worth, as highly promising for future research.

Two different classifications have been presented utilizing the general framework taxonomy presented in Section 1.2. This taxonomy which characterizes the field by its basic building blocks, provides much insight in a simple framework. It is believed that additional classifications based on this taxonomy would engender a greater appreciation of the soundness of the principles that are the foundation of engineering economics.

4.2. Research Priorities Related to the Life-Cycle Taxonomy

In Section 3.1, Figure 4 presents a taxonomy that relates the elements of the methodologies/techniques of engineering economics to the phases of a product's life-cycle. Detailed definitions of each of the row and column elements are presented in Section 3.1 with descriptions of the individual cells given in Appendix C.

The purpose of this section is to demonstrate how this taxonomy might be utilized to classify potential research projects. Again, the prospects to be considered for this demonstration are selected from the proposed future research projects identified at the Mt. Lake, Virginia conference. The listing of these projects and their titles are presented in Table 1 of Appendix A. The rank order of these projects as seen by the academic and industry participants at Mt. Lake is presented in Table 2 of Appendix A. For our example, four of the highest ranked projects will be considered. These projects are:

Rank	Project Number	Project Description
(1)	[26]	Economic Evaluation of Design Trade-Offs Over the Life-Cycle
(2)	[10]	CAD-CAE (Computer Aided Estimating)
(3)	[30]	Economic Modeling of Manufacturing Processes
(5)	[6]	Timing and Locating the Introduction of New Technologies

By shading those cells in the taxonomy primarily affected by each of these research projects, a perspective is achieved regarding the scope of consequences associated with each of these projects. For example, it is observed in Figures 8, 9, 10 and 11 the elements of the taxonomy affected by the four research projects being considered.

Project 26 analyzed in Figure 8 would have a broad impact on the field of engineering economics because it is concerned with technical developments that effect most of the elements in the life-cycle. At the other extreme is project 6 which focuses on strategic issues. It is seen from Figure 11 that the impact of this project is confined to those areas for which there presently exists few quantitative methodologies. Figures 9 and 10 present those elements of engineering economics expected to be impacted by projects 10 and 30, respectively.

This type of analysis could have been applied to all the research areas proposed at the Mt. Lake conference. The result of such an effort could provide interesting and valuable insights regarding the contributions that might be expected from the pursuit of the research areas identified. These insights might prove to be quite useful in planning the development of research programs in engineering economics.

Another benefit of this classification process is that it will assist researchers in understanding how their activities interface with other on-going research. In addition, researchers may find the use of this taxonomy helpful in understanding how their efforts contribute to the overall improvement of the field.

LIFE-CYCLE / METHODOLOGIES/ TECHNIQUES	1. Need Determination	2. Concept Formulation/ Preliminary Design	3. Detail Design/ Development	4. Production/ Construction	5. Operational/ Support	6. Retirement/ Disposal
A. Definition of Alternatives						
B. Forecasting/ Estimating						
C. Cash Flow Development						
D. Analysis/ Evaluation						
E. Recommendation/ Decision						
F. Implementation/ Control						

Figure 8. Classification of Engineering Economics Research by Methodology and Life-Cycle

(Project 26. Economic Evaluation of Design Trade-Offs Over the Life-Cycle)

LIFE-CYCLE / METHODOLOGIES/ TECHNIQUES	1. Need Determination	2. Concept Formulation/ Preliminary Design	3. Detail Design/ Development	4. Production/ Construction	5. Operational/ Support	6. Retirement/ Disposal
A. Definition of Alternatives						
B. Forecasting/ Estimating						
C. Cash Flow Development						
D. Analysis/ Evaluation						
E. Recommendation/ Decision						
F. Implementation/ Control						

Figure 9. Classification of Engineering Economics Research by Methodology and Life-Cycle

(Project 10. CAD-CAE, Computer Aided Estimating)

METHODOLOGIES/ TECHNIQUES \ LIFE-CYCLE	1. Need Determination	2. Concept Formulation/ Preliminary Design	3. Detail Design/ Development	4. Production/ Construction	5. Operational/ Support	6. Retirement/ Disposal
A. Definition of Alternatives						
B. Forecasting/ Estimating						
C. Cash Flow Development						
D. Analysis/ Evaluation						
E. Recommendation/ Decision						
F. Implementation/ Control						

Figure 10. Classification of Engineering Economics Research by Methodology and Life-Cycle

(Project 30. Economic Modeling of Manufacturing Processes for Cost Effective Product Design)

LIFE-CYCLE / METHODOLOGIES/ TECHNIQUES	1. Need Determination	2. Concept Formulation/ Preliminary Design	3. Detail Design/ Development	4. Production/ Construction	5. Operational/ Support	6. Retirement/ Disposal
A. Definition of Alternatives	■	■				
B. Forecasting/ Estimating	■	■				
C. Cash Flow Development						
D. Analysis/ Evaluation						
E. Recommendation/ Decision						
F. Implementation/ Control						

Figure 11. Classification of Engineering Economics Research by Methodology and Life-Cycle

(Project 6. Timing and Locating the Introduction of New Technologies)

V. TERMINOLOGY FOR ENGINEERING ECONOMICS

As with all fields of knowledge, engineering economics has developed over many years a set of terminology that uniquely identifies the important concepts and provides their definition. By examining the terminology of engineering economics it is possible to judge the scope of ideas contained in this body of knowledge. In addition, the definitions of terms provide the means for precisely understanding the concepts and ideas appearing in the literature of the field.

A study of the interactions among other fields of knowledge and engineering economics as presented in Section 2.1 indicates that many concepts are common to these fields. Unfortunately in many instances, common ideas in related fields have been assigned varying terminology. Therefore, to understand the interfaces between fields it is essential that the definitions of terms be precise and accessible. This report provides the terminology of engineering economics to assist in the understanding the scope of the field and to provide insight regarding the important interfaces among the other related fields.

Appendix D of this report contains an extensive glossary of terms and their definitions as used in the field of engineering economics. These definitions are current as they represent the interim terminology report for the Engineering Economy Subdivision of the Institute of Industrial Engineers Committee on ANSI Z94 standards. The revised version of this report will be available in 1988 as the ANSI Z94 standard for engineer economy in Industrial Engineering Terminology published by the Institute of Industrial Engineers, 25 Technology Park/Atlanta, Norcross, Georgia 30092.

APPENDICES

Session 1638

Planning for Research in Engineering Economics

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INTRODUCTION

Engineering activities of analysis and design are not an end in themselves, but are means for satisfying human wants. Thus, engineering has two aspects. One aspect concerns itself with the materials and forces of nature; the other is concerned with the needs of people. Because engineering is practiced in a resource constrained world, it must be closely associated with economics.

In these times of limited capital availability, American industry is facing complex economic decisions about a host of new design and manufacturing technologies. Because of the rapid advance in these technologies, and the lack of an organized research focus on Engineering Economics, a wide gap has developed between the needs of industry and the capability of this important field. Industry continues to rely upon traditional methods and techniques for the economic evaluation of products, processes, and services.

The purpose of this paper is to report on efforts to establish a research agenda for the field of Engineering Economics. It presents the findings of the Research Planning Conference on Engineering Economics held during the period of August 26 to 29, 1984.*

CONFERENCE BACKGROUND

Informal discussion regarding the need to establish a research agenda for the field of Engineering Economics began early in 1983 between the author and Dr. William M. Spurgeon, NSF Director for Production Research. Then, in May, the author took the idea of a research planning conference before a meeting of the Engineering Economy Division of the Institute of Industrial Engineers for evaluation and comment. A preliminary conference was recommended as a first step.

In June of 1983, the author, assisted by Dr. Michael C. Burstein (U. Massachusetts) and Prof. Roger F. de la Mare (U. Bradford, U.K.) prepared a letter proposal to NSF for a preliminary conference. Dr. Spurgeon reacted favorably to the idea of a preliminary conference, but suggested that it be supported by those working in the field. At this point it was decided that an Economic Decision Analysis symposium being considered by the Engineering Economy Division of the American Society for Engineering Education (ASEE EDA Symposium) could meet the objectives envisioned for the preliminary conference.

The ASEE EDA Symposium idea was being promulgated by the Ad Hoc Committee on Future Directions in Engineering Economy, under the chairmanship of Dr. Gerald J. Thuesen (Georgia Tech). Accordingly, Thuesen was added to the planning group. A significant activity of the planning group was a day long meeting between Spurgeon, Fabrycky, Burstein, and Thuesen in Washington in January of 1984. At this meeting, needs perceived by NSF and the objectives sought through the planned ASEE EDA Symposium and the proposed research planning conference were coordinated.

Fifteen engineering professors representing fifteen universities met in Ann Arbor, Michigan, on May 5 and 6, 1984, for the ASEE EDA Symposium. The University of Michigan (Dr. Jack R. Lohmann) served as host. In addition to addressing the objectives envisioned by the Engineering Economy division of ASEE, the Symposium focused on the proposed NSF conference. Drs. Fabrycky, Burstein, and Thuesen led these discussions.

Following the ASEE Symposium, Dr. Fabrycky finalized the proposal to NSF for the research planning conference. Funding was obtained and the NSF Research Planning Conference on Engineering Economics (NSF RPC on Engineering Economics) was held at Mountain Lake, Virginia, with VPI and SU as host.

PRE-CONFERENCE PREPARATION

According to all indications, the NSF RPC on Engineering Economics was very successful. A measure of credit for this success must be attributed to the pre-conference coordination with NSF and with the Engineering Economy Divisions of the Institute of Industrial Engineers and the American Society for Engineering Education. Additionally, pre-conference assignments accepted by potential and actual conference participants provided planning ideas and inputs which contributed to the success. In this section, a brief description of some of the pre-conference preparation activities are described.

*The Research Planning Conference was supported by the National Science Foundation under Grant No. MEA-841659 to VPI and SU with W. J. Fabrycky as Conference Coordinator. This paper is based upon the complete proceedings of the conference published in April, 1985.

Pre-Invitation Reviews

Concurrent with the submission of the proposal to NSF, copies were sent to the 15 ASEE EDA Symposium participants and to two dozen selected academicians and persons in business and industry. Each was asked to review the plans contained therein and to provide suggestions and guidance.

These pre-invitation reviews proved to be very helpful in shaping plans for the NSF RPC on Engineering Economics. The decision to invite all ASEE EDA Symposium participants was made independently of their efforts in this review. However, the reviews received from other academicians and the non-academic reviewers were very useful in deciding who should be included on the final invitee list. The output of these planning reviews was made available to all invitees before the conference.

The Invitees

All fifteen ASEE EDA Symposium participants were invited automatically to the NSF RPC on Engineering Economics. However, since non-academic persons were not in attendance at the ASEE EDA Symposium, priority was given to achieve a mix of academic and non-academic persons at the NSF RPC Conference.

Non-academic persons as well as additional academic persons were invited based upon a demonstrated interest in the goals and objectives of the NSF RPC on Engineering Economics. This interest was indicated in the responses received to the pre-invitation reviews of the proposal.

The final list of participants is given below by name and affiliation. Non-academicians totaled nine, representing a good cross-section of organizations. They were:

Steven Blum (AT&T)
James A. Bontadelli (TVA)
Joel I. Kahn (Procter and Gamble)
Richard A. Leshuk (IBM)
Grady E. Means (Coopers and Lybrand)
Richard A. Miller (GE)
Julian A. Piekarski (PAICE Associates)
James B. Weaver (Venture Services)
Vance K. Wilkinson (Martin Marietta)

Twenty-two academicians participated. Those who also attended the ASEE EDA Symposium are marked with an asterisk.

*Richard H. Bernhard (N.C. State U.)
*Leland T. Blank (Texas A&M U.)
*Thomas O. Boucher (Rutgers U.)
*James R. Buck (U. Iowa)
*Michael C. Burstein (U. Massachusetts)
C. Alec Chang (U. Missouri)
Roger F. de la Mare (U. Bradford)
J. Morley English (U.C.L.A.)
*Wolter J. Fabrycky (VPI and S.U.)
*Charles H. Falkner (U. Wisconsin)
Gerald A. Fleischer (U.S.C.)
Bela Gold (Claremont College)
*Jack R. Lohmann (U. Michigan)
Charles J. Malmborg (VPI and S.U.)
Clark A. Mount-Campbell (Ohio State U.)
*Robert V. Oakford (Stanford U.)
Phillip F. Ostwald (Colorado U.)
*Umesh Saxena (U. Wisconsin-Milwaukee)
*Chan S. Park (Auburn U.)
*Gerald J. Thuesen (Georgia Tech)
Tom M. West (Oregon State U.)
*Thomas L. Ward (U. Louisville)

Dr. William M. Spurgeon (NSF) attended the entire conference and participated in many appropriate and useful ways.

Homework Assignments

All invitees were provided with resource materials before the conference convened on August 26. These materials were: 1) The comments provided by pre-conference reviewers, 2) "Engineering Economy: An Economist's Perspective" by Dr. Ira Horowitz, 3) Comments on Horowitz by Dr. Richard H. Bernhard, 4) "Will Money Managers Wreck the Economy?" (Business Week - August 13, 1984), and 5) A draft framework and draft set of research areas prepared by Dr. Michael Burstein.

Academic participants were asked to prepare a carefully worded one page (single spaced) summary of research currently being conducted. A second page was requested to outline research which the participant would like to do IF HE WERE KING.

Non-academic participants were asked to prepare a carefully worded one page summary of engineering economics as it is practiced currently. A second page was requested describing research results which the participant would like to have IF HE HAD A GENIE.

CONTRIBUTIONS BY INDIVIDUALS

Considerable pre-conference preparation took place as described in the previous section. This preparation made it possible for individuals to contribute from their own experience prior to being "conditioned" by the process of research planning as a group activity.

Challenge Speeches

After a group dinner to open the conference, two speeches were given to set forth several challenges. The first was by Dr. William M. Spurgeon to give his perception of what a good research planning conference should accomplish. Additionally, it offered several suggestions for meeting the needs of the field.

A second speech was then given by an applied economist, Dr. Paul H. Hoepner (VPI and SU). He challenged several of the fundamental concepts promulgated by engineering economists. An analysis and rebuttal is given in the conference proceedings by Dr. Richard H. Bernhard (N. C. State University).

Individual Presentations

Twelve minutes was allocated to each conference participant to present and defend his pre-prepared and pre-submitted area of research emphasis. This was an intense first day effort which served to acquaint participants with the work and viewpoints of all.

Non-academic participants presented individually a summary of engineering economics as it is currently practiced. These participants also individually presented research results which they would have liked to have if they had a genie.

Conference participants from the academic community were asked to individually present a summary of research currently being conducted. A second request of the academic group was for an outline of research which would be pursued if the participant were king.

All participants had, upon arrival, a complete copy of all presentations in single page form. The presentations followed the pre-prepared statements quite closely and set forth "initial conditions" for the group efforts on the second day.

DETERMINATION OF RESEARCH OPPORTUNITIES

The storyboard technique was chosen as the mechanism to facilitate the synthesis of individual contributions. A storyboard is a visual means of planning developed by Walt Disney in 1928. It may be used for creative idea generation and for group planning. The technique facilitates the quick grasp of a problem by a group, aides the creative process, and makes the group output visible.

Conference participants were organized into five storyboard groups, with each group composed of both academic and non-academic persons. Mr. Richard A. Miller (General Electric) provided a brief training session on the storyboard technique and then guided each group during the storyboarding processes. A summary of the research projects opportunities identified by each storyboard group is given in the sections which follow:

Integrating Strategic Considerations

This group began its work by considering the variety of meanings embraced by the concept of strategy integration through engineering economics research. Seven strategy implications identified by the group were: 1) Increased profitability (cost reduction, revenue expansion, or both), 2) Responses to changes in technology, 3) Implications of resource limitations, 4) Impacts of quality improvements and competitiveness, 5) Supporting the growth of the firm, 6) Economic impacts of governments on the firm, and 7) Other implications.

Research opportunity areas identified by this group were derived from the strategic considerations listed. These areas were:

1) Assessing the Cost/Benefits of Manufacturing Flexibility.
2) Timing and Locating the Introduction of New Technology.
3) Economic Evaluation of Anticipated Technologies.
4) Economic Evaluation of Alternative Quality Strategies.
5) Causes of Lag in the Transfer of Defense Technologies to Private Manufacturing.
6) Effects of Technical Innovation on Capital Requirements.
7) Modeling Trade-Offs Between Risks and Growth.

Data Gathering and Analysis

The work of this group was centered on the following objectives: 1) To enhance data resources by analyzing, standardizing, and improving available data, 2) To suggest data collection methods, 3) To provide a basis for productivity improvement and measurement, and 4) To increase knowledge of current industrial practice. Four general areas for future research project focus were defined as: 1) Collection methods and systems, 2) Data analysis, 3) Real world applications, and 4) Facilitating data access.

Seven areas of research opportunity which derived from the objectives and needs listed were:

1) Artificial Intelligence.
2) CAD-CAE (Computer Aided Estimating).
3) Hardware and Software Tradeoffs.
4) Parametric and Shortcut Estimating.
5) Interdependence of Cost Elements.
6) Noisy, Fuzzy Data Clusters.
7) Data Base Networking.

Decision Process of the Firm

This group set forth six areas of consideration for its storyboard effort. These were: 1) Improve the performance of the firm with engineering economics, 2) Identify research areas for further improvement, 3) Integration of engineering economics, finance, and accounting, 4) Integration of engineering economics techniques into functional application areas, 5) Integration of engineering economics techniques into interfunctional processes, and 6) Improving communication between theoreticians and practitioners.

Research opportunity areas identified by this group were derived from the considerations above. These areas were:

1) Survey of Function Applications and Needs.
2) Develop Methodology to Integrate Engineering Economy, Finance, and Accounting Measures for Project Evaluation.
3) Develop Improved Methods for Estimating Project Revenue, Expense, and Investment Cash Flows.
4) Develop Better Measures of Investment Worth.
5) Criteria for Portfolio Evaluation.
6) Study Cost Allocation in High-Tech vs. Other Industries.

Bringing Products and Systems Into Being

This group focused on the improvement of the overall design and development process of new products and systems by injecting economic considerations into the life-cycle through a linking of the design and development process with economic considerations. The identification of the economic merits of new products and systems was considered as a second purpose adopted by this storyboard group.

Research opportunity areas which derived from these purposes were:

1) Economic Relationships with Other Systems.
2) Cost Control (Systems Engineering Management).
3) Methodology for Need Determination.
4) Modeling System Performance/Cost as Impacted by Design.
5) Economic Evaluation of Design Trade-Offs Over the Life-Cycle.
6) Methodology for Treating Risk and Uncertainty.

Manufacturing Technology

This storyboard group established the objective of identifying and prioritizing research projects in engineering economic analysis for manufacturing. The group's purpose was set forth to clarify research objectives in the area of manufacturing, an area in which there is a large potential market and visible industry need. Another purpose identified was to match the research skills of the engineering economics community to those needs to provide deliverables that will help improve manufacturing competitiveness, efficiency, and productivity.

Seven research areas were judged to be most important to the objective and purpose stated. These were:

1) Economic Consequences of Alternative Investments.
2) Economic Modeling of Production Systems.
3) Economic Modeling of Manufacturing Processes for the Purpose of Cost Effective Product Design.
4) Economic Evaluation of Software Selection and Development for Manufacturing Systems.
5) Economic Design of Data Collection Systems in Manufacturing.
6) Appropriate Measures of Effectiveness.
7) State-of-the-Art Literature and Industry Surveys.

DETERMINATION OF RESEARCH PRIORITIES

An overarching objective of the NSF RPC on Engineering Economics was to produce a rank-ordered list of research projects. The ranking task was scheduled for the last morning of the conference and was accomplished by the twenty-nine participants remaining at that time. The paragraphs which follow were adapted from the prioritization process reported in the conference proqeedings by Dr. Clark A. Mount-Campbell (Ohio State).

The storyboard process described resulted in a total of thirty-four projects grouped under five headings:

1) Integrating Strategic Considerations.
2) Data Gathering and Analysis.
3) Decision Process of the Firm.
4) Bringing Products and Systems into Being.
5) Manufacturing Technology.

The first heading (Strategy) had eight projects listed under it. Other headings contained either six or seven projects. To minimize this imbalance the storyboard group who generated the Strategy projects was asked to eliminate one of their eight. As a result, the project that had been arbitrarily numbered one was removed from the list before the collective group of participants were asked to rank all projects. The remaining thirty-three projects were then numbered two through thirty-four.

Participants were asked to select, from the thirty-three projects, the eight that they thought to be more important than the others. Next they were asked to rank order their eight selected projects and to assign scores of 8, 7, ..., 1, with the most important project receiving an 8 and the least important project receiving a 1. If a project was included in an individual's list of eight, then it is considered to have received a vote regardless of what score it received. Thus, there are two ways to prioritize the entire list based on the information gathered from the participants. First, a ranking can be established by the sum of the scores given by all participants. Second, a ranking can be established by the number of votes each project received. The recommended ranking is based on the sum of scores, but the results were tabulated both ways.

Additional information was gathered during the ranking procedure by asking all participants to mark their ballots with either "academia" or "industry" depending on their particular backgrounds. The results of the ranking and voting process are given with this categorization.

Table 1 summarizes the rank-sum scores of all individuals, grouped by background (academia/industry). The projects in Table 1 are listed in their original order and are grouped under their storyboard headings. Table 2 contains the same information as Table 1, but in Table 2 the projects are ordered according to the sum of their scores (the storyboard headings have been dropped.

One may note from Table 2 that the first priority project earned its position almost entirely on the strength of the high score given it by the academic group while the industry group scored it below six other projects. Also, the first and second highest priority projects among the industry group scored fourth and sixth among the academic group while the third, fourth, and fifth most important projects to the industry group were well down the list for the academic group.

Table 3 gives the thirty-three projects ranked in an order determined by the number of votes given each project, instead of by rank-sum score. The rank-sum score was used to break ties in the voting. A Spearman rank correlation coefficient was computed using the rankings in Tables 2 and 3 but without breaking ties. The correlation coefficient was 0.93.

TABLE 1: RANK SUMS BY ACADEMIC AND INDUSTRY PARTICIPANTS

RESEARCH AREAS/PROJECTS	SCORES (ACADEMIA)	SUB-TOTAL	SCORES (INDUSTRY)	SUB-TOTAL	TOTAL
INTEGRATING STRATEGIC CONSIDERATIONS					
2. Modeling Trade-Offs Between Risk and Growth	3 3	6	3 1	4	10
3. Economic Eval. of Alternative Quality Strategies	8 5 2	15	8 8 4 2	22	37
4. Effects of Tech. Innovation on Capital Requirements	5 5 4 4 4 3	25		0	25
5. Causes of Lag in Transfer of Defense Tech. to Private Mfg.		0		0	0
6. Timing and Locating the Intro. of New Technologies	8 8 6 6 5 4 2 2 2	43	8 3	11	54
7. Economic Eval. of Anticipated Technologies	8 8 7 7 4 4 1 1	40	4	4	44
8. Assess Cost/Benefits of Mfg. Flexibility	8 8 7 6 6 6 5 3	49	1	1	50
DATA GATHERING AND ANALYSIS					
9. Artificial Intelligence	6 4 3	13	5 3	8	21
10. CAD-CAE (Computer Aided Est.)	8 7 7 7 7 6 4	46	8 7 7 6 2	30	76
11. Hardware and Software Trade-Offs	5 5 3	13	6	6	19
12. Parametric and Shortcut Est.	6 5 4 4 3	22	7 6 4 2	19	41
13. Interdependence of Cost Elements	5	5	7 4	11	16
14. Noisy, Fuzzy Data Clusters	2 2	4		0	4
15. Data Base Networking	5 3	8		0	8
DECISION PROCESS OF THE FIRM					
16. Develop Improved Methods for Est. Proj. Revenues-Expense, etc.	7 5	12	6 6	12	24
17. Study Cost Allocation in High Tech vs. Other Industries	8 2 2 1	13	5 4 2	11	24
18. Dev. Better Methods of Investment Worth and Compare	8 8 8 2 1 1	28		0	28
19. Dev. Method to Integrate EE with Finance and Acct. Measures	6 6 5 5 3 3 1 1 1	31	7 7 4	18	49
20. Criteria for Project Evaluation	4 4 4 3 3 1	19	3	3	22
21. Survey of Function Applications and Needs	8 6 3	17	8 8	16	33
BRINGING PRODUCTS AND SYSTEMS INTO BEING					
22. Economic Relationships With Other Systems	7 7	14	5	5	19
23. Cost Control (Systems Engineering Management)	4 3 1	8		0	8
24. Methodology of Need Determination	5 4 3	12		0	12

25. Model System Performance - Cost As Impacted by Design	6 6 6 5 2 2	27		0	27
26. Econ. Eval. of Design Trade-Offs Over the Life-Cycle	8 8 8 7 7 5 5 5 4 3 2 2 1 1	66	7 5 1 1	14	80
27. Methodology for Treating Risk and Uncertainty	7 6 6 5 4 2	30	3 2	5	35
MANUFACTURING TECHNOLOGY					
28. Econ. Consequences of Alter. Investments	7 4 3 1 1 1	17		0	17
29. Econ. Modeling for Production Systems	8 8 8 7 6 6 4 4 3	54	6 3	9	63
30. Economic Modeling of Mfg. Processes (Product)	7 7 7 7 6 4 2 1	41	8 6 5 5 3	27	68
31. Econ. Eval. of Software Dev. for Mfg. Systems	7 5 4 3 2 2 1 1 1	26		0	26
32. Econ. Design of Data Collection Systems in Mfg.	8 6 5 3 3 2 2	29	1	1	30
33. Approp. Measures of Effectiveness (Taxonomy)	7 7 6 2 1 1 1	25	2 1	3	28
34. State-of-the-Art Survey and Search	8 8 5 3 2 2	29	5 4 2 1	12	40

TABLE 2: ORDERED RANK SUMS BY ACADEMIC AND INDUSTRY PARTICIPANTS

RESEARCH AREAS/PROJECTS	SCORES (ACADEMIA)	SUB-TOTAL	SCORES (INDUSTRY)	SUB-TOTAL	TOTAL
26. Econ. Eval. of Design Trade-Offs Over the Life-Cycle	8 8 8 7 7 5 5 5 4 3 2 2 1 1	66	7 5 1 1	14	80
10. CAD-CAE (Computer Aided Est.)	8 7 7 7 7 6 4	46	8 7 7 6 2	30	76
30. Econ. Modeling of Mfg. Processes (Product)	7 7 7 7 6 4 2 1	41	8 6 5 5 3	27	69
29. Econ. Modeling for Prod. Systems	8 8 8 7 6 6 4 4 3	54	6 3	9	67
6. Timing and Locating the Intro. of New Technologies	8 8 6 6 5 4 2 2 2	43	8 3	11	54
8. Assess Cost/Benefits of Mfg. Flexibility	8 8 7 6 6 6 5 3	49	1	1	50
19. Dev. Method to Integrate EE with Finance and Acct. Measures	6 6 5 5 3 3 1 1 1	31	7 7 4	18	49
7. Econ. Eval. of Anticipated Technologies	9 8 7 7 4 4 1 1	40	4	4	44
12. Parametric and Shortcut Est. Techniques	6 5 4 4 3	22	7 6 4 2	19	41
34. State-of-the-Art Survey and Search	8 8 5 3 2 2	28	5 4 2 1	12	40
3. Econ. Eval. of Alternative Quality Strategies	8 5 2	15	8 8 4 2	22	37
27. Methodology for Treating Risk	7 6 6 5 4 2	30	3 2	5	35
21. Survey of Function Applications and Needs	8 6 3	17	8 8	16	33
32. Econ. Design of Data Collection Systems in Mfg.	8 6 5 3 3 2 2	29	1	1	30
33. Approp. Measures of Effectiveness (Taxonomy)	7 7 6 2 1 1 1	25	2 1	3	28
18. Dev. Better Methods of Investment Worth and Compare	8 8 8 2 1 1	28		0	28
25. Model System Performance - Cost as Impacted by Design	6 6 6 5 2 2	27		0	27

31. Econ. Eval. of Software Development for Mfg.	7 5 4 3 2 2 1 1 1	26		0	26
4. Effects of Tech. Innovation on Capital Requirements	5 5 4 4 4 3	25		0	25
17. Study Cost Allocation in High Tech vs. Other Industries	8 2 2 1	13	5 4 2	11	24
16. Dev. Improved Methods for Est. Proj. Revenues-Expense, Etc.	7 5	12	6 6	12	24
20. Criteria for Project Evaluation	4 4 4 3 3 1	19	3	3	22
9. Artificial Intelligence	6 4 3	13	5 3	8	21
11. Hardware and Software Trade-Offs	5 5 3	13	6	6	19
22. Economic Relationship with Other Systems	7 7	14	5	5	19
28. Econ. Consequences of Alternative Investments	7 4 3 1 1 1	17		0	17
13. Interdependence of Cost Elements	5	5	7 4	11	16
24. Methodology of Need Determination	5 4 3	12		0	12
2. How to Model Trade-Off Between Risk and Growth	3 3	6	3 1	4	10
23. Cost Control (Systems Engineering Management)	4 3 1	8		0	8
15. Data Base Networking	5 3	8		0	8
14. Noisy, Fuzzy Data Clusters	2 2	4		0	4
5. Causes of Lag in Trans. of Defense Tech. to Private Mfg.		0		0	0

TABLE 3: RANK SUMS ORDERED BY NUMBER OF VOTES

RESEARCH AREAS/PROJECTS	INDIVIDUAL SCORES	TOTAL SCORE	TOTAL SCORE
26. Econ. Eval. of Design Trade-Offs Over the Life-Cycle	8 8 8 7 7 7 5 5 5 5 4 3 2 2 1 1 1 1	80	18
30. Econ. Modeling of Mfg. Processes (Product)	8 7 7 7 7 6 6 5 5 4 3 2 1	68	13
10. CAD/CAE (Computer Aided Est.)	8 8 7 7 7 7 7 7 6 6 4 2	76	12
19. Dev. Method to Integrate EE with Finance and Acct. Measures	7 7 6 6 5 5 4 3 3 1 1 1	49	12
29. Econ. Modeling for Prod. Systems	8 8 8 7 6 6 6 4 4 3 3	63	11
6. Timing and Locating the Intro. of New Technologies	8 8 8 6 6 5 4 3 2 2 2	54	11
34. State-of-the-Art Survey and Search	8 8 5 5 4 3 2 2 2 1	40	10
8. Assess Cost/Benefits of Mfg. Flexibility	8 8 7 6 6 6 5 3 1	50	9
7. Econ. Evaluation of Anticipated Technologies	8 8 7 7 4 4 4 1 1	44	9
12. Parametric and Shortcut Est. Techniques	7 6 6 5 4 4 4 3 2	41	9
33. Approp. Measures of Effectiveness (Taxonomy)	7 7 6 2 2 1 1 1 1	28	9
31. Econ. Eval. of Software Dev. for Mfg.	7 5 4 3 2 2 1 1 1	26	9

27. Methodology for Treating Risk	7 6 6 5 4 3 2 2	35	8
32. Econ. Design of Data Collection Systems in Mfg.	8 6 5 3 3 2 2 1	30	8
3. Econ. Eval. of Alternative Quality Strategies	8 8 8 5 4 2 2	37	7
17. Study Cost Allocation in High Tech vs. Other Industries	8 5 4 2 2 2 1	24	7
20. Criteria for Project Evaluation	4 4 4 3 3 3 1	22	7
18. Dev. Better Methods of Investment Worth and Compare	8 8 8 2 1 1	28	6
25. Model System Performance - Cost as Impacted by Design	6 6 6 5 2 2	27	6
4. Effects of Tech. Innovation on Capital Requirements	5 5 4 4 4 3	25	6
28. Econ. Consequences of Alternative Investments	7 4 3 1 1 1	17	6
21. Survey of Function Applications and Needs	8 8 8 6 3	33	5
9. Artificial Intelligence	6 5 4 3 3	21	5
16. Dev. Improved Methods for Est. Proj. Revenues-Expense, Etc.	7 6 6 5	24	4
11. Hardware and Software Trade-Offs	6 5 5 3	19	4
2. How to Model Trade-Off Between Risk and Growth	3 3 3 1	10	4
22. Econ. Relationship with Other Systems	7 7 5	19	3
13. Interdependence of Cost Elements	7 5 4	16	3
24. Methodology of Need Determination	5 4 3	12	3
23. Cost Control (Systems Engineering Management)	4 3 1	8	3
15. Data Base Networking	5 3	8	2
14. Noisy, Fuzzy Data Clusters	2 2	4	2
5. Causes of Lag in Transfer of Defense Tech. to Private Mfg.		0	0

SUMMARY AND CONCLUSIONS

Engineering Economics for design and/or manufacturing ranked very high in the NSF RPC on Engineering Economics. In all, there were 33 project areas prioritized from among hundreds considered. In the top one-third of these (11 projects), one finds eight which deal with design or manufacturing. In priority order, these are:

1) Economic Evaluation of Design Trade-Offs Over the Life-Cycle
2) CAD-CAE (Computer Aided Estimating).
3) Economic Modeling of Manufacturing Processes.
4) Economic Modeling for Production Systems.
5) Timing and Locaitng the Introduction of New Technologies.
6) Assess Cost/Benefits of Manufacturing Flexibility.
7) Economic Evaluation of Anticipated Technologies.
8) Economic Evaluation of Alternative Quality Strategies.

Among the eleven project areas ranked in the middle third of the 33 projects prioritized, six deal with design and/or manufacturing. In priority order, these are:

1) Economic Design of Data Collection Systems in Manufacturing.
2) Model System Performance - Cost as Impacted by Design.
3) Economic Evaluation of Software Development for Manufacturing.
4) Develop Improved Methods for Estimating Project Revenues - Expenses, Etc.
5) Effects of Technical Innovation on Capital Requirements.
6) Criteria for Project Evaluation.

In the lowest thrid of the 33 project areas, one finds two which deal with design or manufacturing. In priority order, these are:

1) Hardware and Software Trade-Offs.
2) Causes of Lag in Transfer of Defense Technologies to Private Manufacturing.

The host of new design and manufacturing technologies facing American industry are raising complex economic questions. Accordingly, it was reasonable to expect that half of the high priority resarch project areas identified would deal with design and or manufacturing as summarized above.

Economic feasibility is generally acknowledged to be the essential prerequisite for successful engineering application. Accordingly, engineers in design and manufacturing must assume a greater responsibility for the economic consequences of thier decisions. The need for progress through research in Engineering Economics has never been greater.

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1) Proceedings, Research Planning Conference on Engineering Economics, Edited by W. J. Fabrycky, VPI and State University, April, 1985.

2) Fabrycky, W. J., "The Research Planning Conference on Engineering Economics," Proceedings, 1985 Manufacturing Systems Research Conference, Madison, Wisconsin, April, 1985.

3) Thuesen, G. J. and W. J. Fabrycky, Engineering Economy, Sixth Edition, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1984.

WOLTER J. FABRYCKY

W. J. Fabrycky is Professor of Industrial Engineering and Operations Research at Virginia Polytechnic Institute and State University. He received the Ph.D. in Engineering in 1962 from Oklahoma State University, the M.S. in Industrial Engineering in 1958 from the University of Arkansas, and the B.S. in Industrial Engineering in 1957 from Wichita State University.

Dr. Fabrycky has served as a Vice President and a member of the Board of Directors of both the American Society for Engineering Education and the American Institute of Industrial Engineers. He was elected to the rank of Fellow in the American Institute of Industrial Engineers in 1978 and to the rank of Fellow in the American Association for the Advancement of Science in 1980. Dr. Fabrycky is co-editor of the Prentice-Hall International Series in Industrial and Systems Engineering.

APPENDIX B

PLANNING CONFERENCE FOR DEVELOPING A RESEARCH FRAMEWORK FOR ENGINEERING ECONOMICS

AGENDA
Thursday, March 28, 1985

Welcome Dr. G.J. Thuesen

Review of NSF Dr. William Spurgeon

Purpose and Goals of Planning Conference

I. Scope of Engineering Economics
   Reports of participants on pre-meeting assignments
   Assignments of discussion groups

   Break

   Development of definitions and interface relationships

   Lunch

   Report of discussion groups
   Conclusions

   Break

II. Taxonomies and Classification Systems

   Discussion of general principles of classification systems
   Reports of participants on pre-meeting assignments
   Assignment of discussion groups
   Development of taxonomies

PLANNING CONFERENCE FOR DEVELOPING A RESEARCH FRAMEWORK FOR ENGINEERING ECONOMICS

Agenda
Friday, March 29, 1985

II. Taxonomies and Classification Systems (continued)
  Development of Taxonomies

Break

  Report of discussion groups

Lunch

  Conclusions

III. Standard terms and definitions
  Review of ANSI Standard

Break

  Group discussion

IV. Pre-planning for 2nd Meeting
  What should be the homework assignments?
  When and where should the 2nd meeting be held.
  What should be the agenda for the 2nd meeting.

Pre-meeting Assignments

Each participant should prepare a written reponse to the appropriate questions and be prepared to discuss these on Thursday March 28th.

1. Read the purpose, plan and conference results that are expected from this planning conference. (Enclosure I)

2. Read the Framework of the Field prepared by Mike Burstein for the proceedings of the Mt. Lake Conference. (Enclosure II)

3. Examine the classification schemes presented to develop a sense of the variety of taxonomies available. (Enclosure III)

4. Examine the classification scheme regarding the elements within the field. A partial listing of elements is provided from The Engineering Economist. Also included are the Table of Contents from two text books in the field. (Enclosure IV)

5. Examine the classification scheme for defining the scope of the field and the adjacent and overlapping fields of knowledge. Read the paper by James Buck. (Enclosure V)

6. Review the papers by Horowitz and Bernhard provided as reading for Mt. Lake Conference. Also of use is the report from the Workshop on Economics in Engineering Systems. This report was a part of the material provided at the Mt. Lake Conference.

7. Prepare 2 systems of classification for grouping the elements in the field. Use Enclosure IV for a partial listing of these elements.

8. Prepare a general definition of the field in two paragraphs or less.

9. Identify the boundaries of the field of engineering economics based on subject matter. Provide a scheme for presenting the interfaces among the other fields having important relationships with engineering economics (e.g. Accounting, finance, computer science, math programming, etc.)

10. Develop one other scheme for defining the field of engineering economics. Use this scheme to present the interfaces among those elements related to but external to engineering economics. (eg. research, development, design, production, etc.)

GEORGIA TECH 1885-1985

DESIGNING TOMORROW TODAY

Georgia Institute of Technology
School of Industrial and Systems Engineering
Atlanta, Georgia 30332-0205
(404) 894-2300

April 9, 1985

■

Dear ■:

I want to thank you for your contribution to the first round of the Planning Conference for Developing a Research Framework for Engineering Economics. Your enthusiasim and hard work has resulted in substantial progress towards the goals of this endeavor.

The assignments made on March 29, 1985 in Atlanta to prepare us for our second meeting on May 3rd and 4th in Washington, D.C. are as follows:

<u>Jim Bontadelli</u>

The flow chart description placed on the board describing the interactions of change in profit and the problems of cost control dealt with the production phase of the life cycle. (See Enclosure 1)

New task 1: Develop a similar description of the <u>design</u> activity within the life cycle.
New task 2: Expand the detail of Enclosure 1.

<u>Mike Burstein</u>

Given the matrix of Methodology vs. Life Cycle (Enclosure II) and the prioritized research areas developed at Mt. Lake, assign those areas within the matrix. Also identify any new research areas overlooked at Mt. Lake that have become evident since our meeting in Atlanta.

Wolt Fabrycky

Using the matrix form of Methodology vs. Life Cycle (Enclosure II) define the present status of the engineering economics profession. Elaborate on the elements in the matrix with details using the current status perspective.

Richard Leshuk

Using the matrix form of Methodology vs. Life Cycle (Enclosure II) define the future opportunities of the engineering econmics profession. Elaborate on the elements in the matrix with details using the future opportunity perspective.

Grady Means

The flow chart description placed on the board describing the interactions of change in profit and the problems of cost control dealt with the production phase of the life cycle.
(See Enclosure 1)

New Task 1: Develop a similar description of the design activity within the life cycle.
New Task 2: Expand the detail of Enclosure I.

Jerry Thuesen

Elaborate on the description of the fundamentals of the body of knowledge referred to as engineering economics. Develop a detailed description of the interfaces between the other disciplines and engineering economics. This description should include a visual representation.

It is important that we be prepared before the Washington D.C. meeting as this is to be the last time that we will meet as a group. Your conscientious effort before our Atlanta meeting enabled us to make substantial progress. A similar effort for the Washington D.C. meeting will help ensure the successful completion of our assigned tasks.

I have made reservations for Bontadelli, Burstein, Fabrycky and Thuesen at the State Plaza Hotel, 2117 E. Street, N.W. Washington D.C. 20037 Telephone (202) 861-8200. Each person staying at the hotel should confirm these reservations and guarantee them if you are arriving after 6:00 p.m. The reservations are for Thursday, May 1st and Friday, May 2nd.

We will begin our meeting at 9:00 a.m. on Friday, May 2. Meet at Dr. Spurgeon's office at the National Science Foundation just before 9:00 a.m. and we will go from there to the Conference room we have been assigned.

I look forward to our resumption and completion of the effort in Washington, D.C. With the support of NSF the field of engineering economics not only has the opportunity of identifying the important research issues and research areas of the future but of placing these research activities in their proper context. I believe the improved understanding that will result from these efforts will significantly enhance the ability of engineering economics to deliver when the demands of the next decade are upon us.

Sincerely,

Gerald Thuesen

GJT/mb

Enclosures

PLANNING CONFERENCE FOR DEVELOPING A RESEARCH FRAMEWORK FOR ENGINEERING ECONOMICS

AGENDA

Friday, May 3, 1985

I. Review of Purpose and Goals

II. Review of Individual Assignments

1. Fundamentals and interfaces between disciplines, Thuesen.
2. Present the <u>current status</u> of engineering economics within the framework of Methodology vs. Life Cycle, Fabrycky.
3. Present the <u>future opportunities</u> of engineering economics within the framework of Methodology vs. Life Cycle, Leshuk.
4. Present priortized research areas within the framework of Methodology vs. Life Cycle, Burstein.
5. Present the details regarding the interactions between profit and cost control activities, Bontadelli and Means.

III. Identify the Tasks Remaining to be Completed to Produce NSF Final Report (See Conference Results)

1. Assign tasks to be completed.
    a. Develop specific outlines of work
    b. Work tasks to completion

IV. Review the Work Completed

V. Fit the Pieces Together

VI. Make the Final Writing Assignments

PLANNING CONFERENCE FOR DEVELOPING A RESEARCH

FRAMEWORK FOR ENGINEERING ECONOMICS

AGENDA

Saturday, May 4, 1985

I. Review the Needs for the NSF Seminar

   1. Discuss audience

   2. Type of presentation

   3. Pitfalls

II. Prepare Outline of Presentation

III. Make Assignments to Complete Tasks for Seminar

IV. Review the Needs of the Profession

V. Prepare Outline of Tasks to be Undertaken by Profession

Conference Results

1. Written definition of the scope of engieering economics

    a. Present status (What it is!)

    b. Future status (What it should be!)

2. A written description of the interfaces between engineering economics and other disciplines.

    a. Interfaces among bodies of knowledge

        1. Listing of interfaces

        2. Visual presentation

    b. Interfaces among academia curricula

    c. Interfaces among courses in engineering curricula

3. Written description of taxonomies to aid understanding of field.

    a. Methodology vs. Life-Cycle

        1. Present status

        2. Future status

    b. Methodology vs. Reporting and Control Systems

    c. Methodology vs. Design Function

4. Written description of recent development in engineering economics

    1. Theoretical developments

    2. Methodology/Techniques

    3. Applications

5. Written glossary of standard terms and definitions

6. Summary of planning conference accomplishments

    1. Perceptions

    2. Opinions

APPENDIX C

Summary of matrix cells for Methodology/Techniques vs. Life Cycle The summary information for each cell has been developed from the perspective of "current engineering economy methodology, techniques, and practice."

Row A: Definition of Alternatives

A1: Need/Determination

The need determination (or economics want definition) step is primarily an external process to engineering economy application and practice. The results, however, are the basis for the definition of alternatives in the conceptual/preliminary design phase.

A2: Concept Formulation/Preliminary Design

In this step the need is tranformed into a mutually exclusive set of comparable concept design alternatives. Various structured techniques, are used to develop the mutually exclusive set alternatives from the total independent or dependent alternatives that need to be considered.

A3: Detailed Design/Development

Same as A2, except the selected concept design alternative is the basis for the detail design alternative instead of the need. For the various parts of the product, structure, or system desgin, mutually exclusive sets of detailed design alternatives are developed (to assist decisionmaking on design detail and development). Again, various structured techniques are used to develop the mutually exclusive set of alternatives in each case form the total independent or dependent alternatives that need to be considered.

A4: Production/Construction

Same as A3, except during this phase of the life cycle, the emphasis is cost reduction (i.e., improvement opportunities). The focus is an improvement area and the develoment of the mutually exclusive set of alternatives for accomplishing needed improvement.

A5: Operations/Support

Same as A4, except the initial concern in this phase is developing the mutually exclusive set of operations and support alternatives needed for the product, structure, or system. Then, the emphasis is on continuing improvement areas.

A6: Retirement/Disposal

Same as A5, except the mutually exclusive set of alternatives for any retirement or disposal actions is developed.

Row B: Forecasting/Estimating

B1: Need Determination

Not applicable.

B2: Concept Formulation/Preliminary Design

The objective is credible preliminary cost estimates for use in analysis of the mutually exclusive set of concept design alternatives developed in A2. The prospective costs are estimated using company or industry historical data, comparison with other known design, application of unit cost factors (per square foot, per pound, etc.) macro cost and time estimating relationships, or some combination of these methods. The total estimated cost for a concept/preliminary design alternative is developed by applying these methods within the major cost areas.

B3: Detailed Design/Development

For the detailed design alternatives of this phase, cost estimating uses the "cost buildup" type methods. Standard cost and time data, bill of materials information and vendor quotes, micro cost and time estimating methods, and the factor method are applied. These progressively more detailed cost estimates are then used in analysis of the mutually exclusive sets of alternatives developed for various parts of the overall design.

B4: Production/Construction

Structured forecasting and cost tracking techniques are used in the production/construction phase to monitor costs, estimate the cost impact of changes, and accomplish cost variance analysis. Estimating the cost impact of improvemnt alternatives also is done using the more detailed methods delineated in B3.

B5: Operation/Support

Estimating the cost impacts of improvement alternatives is a primary activity. Estimating maintenance and related costs is critical in this phase. The more detailed methods delineated in B3 are used as well as detailed information on equipment reliability and maintenance history.

B6: Retirement/Disposal

Estimating the costs and revenue consequences of the retirement/disposal alternatives, usig the more detailed methods of B3, is the primary activity.

C: Cash Flow Development

The economic consequences of alternatives are described by their cash flows. The basis structure of a cash flow is general. The content and level of detail of a cash flow is specific to the alternative and the phase of the life cycle involved.

C1: Need Determination

Not applicable.

C2: Concept Formulation/Preliminary Design

Cash flow development is based on the cost estimating described in B2. The elements of the cash flow are the major cost areas. The macro/parametric methods used in B2 permit, in this phase, sensitivity analysis for determining an acceptable cash flow profile to prescreen the concept design alternatives prior to further analysis (Row D).

C3: Detail Design/Development

Cash flow development in this phase reflects the progressive cost detail available from B3. Cash flows for the detailed design alternatives for the various parts of the total design are developed.

C4: Production/Construction

Cost/volume and cost/construction rate relationships may be used to reflect the primary cash flow requirments of this period.

C5: Operations/Support

Cash flows for this phase primarily reflect the reliability and maintainability of the equipment and operating and support efficiencies.

C6: Retirement/Disposal

Alternative cash flows in this phase reflect the cost detail available from B6.

Row D: Analysis

D1: Need Determination

Not applicable.

D2: Formulation Conceptual/Preliminary Design

Focus on technical characteristics and ignores important cost considerations. Optimization of technical performance.

D3: Detailed Design/Development

Consider the trade-offs between technical and economic effects at detailed level. Make or buy decisions for components.

D4: Production/Construction

Traditional application of a variety of methodologies and techniques for evaluation of capital investment alternatives. Use of after-tax cash flow analysis describe the investment options with the accompanying present worth, internal rate of return calculations, is the standard method of analysis in industry today. Techniques of risk analysis and decision analysis have also found considerable application.

D5: Operations/Support

A number of conventional methodologies including break even analysis, and replacement analysis are currently applied by industry. Well known methodologies have been applied to assist in pricing, operating and support decison. Use of optimization techniques for these activities has also been increasing.

D6: Retirement/Disposal

The well known techniques of replacemnt analysis are currently applied by industry although not on a consistant basis. Abandonment models have been developed in the literature of the field but are not utilized by industry.

Row E: Recommendation/Decision

E1: Need Determination

Not applicable.

E2: Concept Formulation/Preliminary Design

Based upon comparison analysis of various alternative design options, based upon standard techniques, recommendations can be made on which design options to pursue.

E3: Detailed Design/Development

Selection of a detailed design alternative(s) could be developed along the same lines of the Conceptual Preliminary Design. Analysis should include total cost of manufacture (including inventory and capital costs) and expected impact of design on market attractiveness and price. If issues such as reliability and quality are relevant to price (inc. servicing) they should be included.

E4: Production/Construction

Decisions on construction should be based on cash flow and net profit (present value) -- if it is a successful profit, exceeding selected handle rates (return) and it fits into the strateges direction of its firm (not an E.E. problem), it should proceed if it fits within the capital budget.

E5: Operations/Support

Decisions regarding maintenance, operating levels and pricing rely on the techniques of breakeven analysis, standard costs, and value added analysis.

E6: Retirement/Disposal

Comparative analysis of existing equipment vs. alternatives (perhaps new technology) was a full assessment of phase out costs vs. replacement costs -- salvage value, etc.

Row F: Implementation/Control

F1: Needs Determination

Not applicable.

F2: Concept Formulation/Preliminary Design

F3: Detailed Design/Development

F4: Production/Construction

Application of cost analyses techniques to renew of standard costs, cost reporting systems, and other areas of management information systems, etc. in order to improve operational and financial control over the project. Use of E.E. techniques to assess value of installing MRP systems, JIT, and other new manufacturing techniques.

F5: Retirement/Disposal

Techniques of post-audit help develop the means for controlling future projects. Life studies combined with the techniques of analysing replacement and abandonment are of use here.

APPENDIX D

Part (b) TERMINOLOGY
GLOSSARY OF TECHNICAL TERMS USED IN ENGINEERING ECONOMY

accounting life The period of time over which the amount of asset cost to be depreciated, or recovered, will be allocated to expenses by accountants.

actual dollars (current dollars, then current dollars) Estimates of future cash flows which include any anticipated changes in amount due to inflationary or deflationary effects.

alternative, contingent An alternative which is feasible only if some other alternative is accepted. The opposite of a mutually exclusive alternative.

alternative, economic A plan, project, or course of action intended to accomplish some objective and has or will be valued in monetary terms.

alternative, independent An alternative such that its acceptance has no influence on the acceptance of other alternatives under consideration.

alternative, mutually exclusive An alternative such that its selection rules out the selection of any other alternatives under consideration.

amortization (1) a) As applied to a capitalized asset, the distribution of the initial cost by periodic charges to expenses as in depreciation. Most amortizable assets have no fixed life. b) The reduction of a debt by either periodic or irregular payments. (2) A plan to pay off a financial obligation according to some prearranged program.

annual equivalent In time value of money, one of a sequence of equal end-of-year payments which would have the same financial effect when interest is considered as another payment or sequence of payments which are not necessarily equal in amount or equally spaced in time.

annuity (1) An amount of money payable to a beneficiary at regular intervals for a prescribed period of time out of a fund reserved for that purpose. (2) A series of equal payments occurring at equally spaced periods of time.

annuity factor The function of interest rate and time that determines the amount of periodic annuity that may be paid out of a given fund. (See capital recovery factor.)

annuity fund A fund that is reserved for payment of annuities. The present worth of funds required to support future annuity payments.

annuity fund factor The function of interest rate and time that determines the present worth of funds required to support a specified schedule of annuity payments. See present worth factor, uniform series.)

apportion In accounting or budgeting, the process by which a cash receipt or disbursement is divided among and assigned to specific time periods, individuals, organization units, products, projects, services, or orders.

Bayesian statistics (1) classical - The use of probabilistic prior information and evidence about a process to predict probabilities of future events. (2) subjective - The use of subjective forecasts to predict probabilities of future events.

benefit-cost (cost-benefit) analysis An analysis technique in which the consequences on an investment evaluated in monetary terms are divided into separate categories of costs and benefits. Each category is then converted into an annual equivalent or present worth for analysis purposes.

benefit-cost ratio A measure of project worth in which the equivalent benefits are divided by the equivalent costs.

benefit-cost ratio method See benefit-cost analysis.

book value The original cost of an asset or group of assets less the accumulated book depreciation.

break-even chart (1) A graphic representation of the relation between total income and total costs for various levels of production and sales indicating areas of profit and loss. (2) Graphic representation of a figure of merit as a function of a specified relevant parameter.

break-even point (1) The rates of operations, output, or sales at which income will just cover costs. Discounting may or may not be used in making these calculations. (2) The value of a parameter such that two courses of action result in an equal value for the figure of merit.

capacity factor (1) The ratio of current output to maximum capacity of the production unit. (2) In electric utility operations, it is the ratio of the average load carried during a period of time divided by the installed rating of the equipment carrying the load. (Also see demand factor and load factor.)

capital (1) The financial resources involved in establishing and sustaining an enterprise or project. (2) A term describing wealth which may be utilized to economic advantage. The form that this wealth takes may be as cash, land, equipment, patents, raw materials, finished products, etc. (Also see investment and working capital.)

capital budgeting The process by which organizations periodically allocate investment funds to proposed plans, programs, or projects.

capital recovery (1) Charging periodically to operations amounts that will ultimately equal the amount of capital expended. (2) The replacement of the original cost of asset plus interest. (3) The process of regaining the new investment in a project by means of setting revenues in excess of the economic investment costs. (Also see amortization, depletion, and depreciation.)

capital recovery factor A number, which is a function of time and interest rate, and is used to convert a present sum to an equivalent uniform annual series of end-of-period cash flows. (Also see annuity factor.)

capital recovery with return The recovery of an original investment with interest. In the public utility industry frequently this is referred to as the revenue requirements approach.

capitalized asset Any asset capitalized on the books of account of an enterprise.

capitalized cost (1) The present worth of a uniform series of periodic costs that continue for an indefinitely long time (hypothetically infinite). Not to be confused with capitalized expenditure. (2) The present sum of capital which, if invested in a fund earning a stipulated interest rate, will be sufficient to provide for all payments required to replace and/or maintain an asset in perpetual service.

cash flow The real monetary units (e.g., dollars) passing into and out of a financial venture.

cash flow diagram The illustration of cash flows (usually vertical arrows) on a horizontal line where the scale along the line is divided into time period units.

cash flow table A listing of cash flows, positive and negative, in a table in order of the time period in which the cash flow occurs.

challenger In replacement analysis, a proposed property or equipment which is being considered as a replacement for the presently owned property or equipment (the defender). In the analysis of multiple alternatives, an alternative under consideration which is to be compared with the last acceptable alternative (the defender).

common costs In accounting, costs which cannot be identified with a given output of products, operations, or services. Expenditures which are common to all alternatives.

compound amount (1) The equivalent value, including interest, at some stipulated time in the future of a series of cash flows occurring prior to that time. (2) The monetary sum which is equivalent to a single (or a series of) prior sum(s) when interest is compounded at a given rate.

compound amount factor Functions of interest and time which, when multiplied by a single cash flow (single payment compound amount factor) or a uniform series of cash flows (uniform series compound amount factor) will give the future worth at compound interest of such single cash flow or series.

compound interest (1) The type of interest that is periodically added to the amount of investment (or loan) so that subsequent interest is based on the cumulative amount. (2) The interest charges under the condition that interest is charged on any previous interest earned in any time period, as well as on the principal.

compounding, continuous A compound interest situation in which the compounding period is of infinitesimal length and the number of periods is infinitely great. A mathematical concept that is practical for dealing with frequent (e.g., daily) compounding periods within a year.

compounding, discrete A compound interest situation in which the compounding period is of specified length such as a day, week, month, quarter year, half year, or year.

compounding period The time interval between dates at which interest is paid and added to the amount of an investment or loan. Usually designates the frequency of compounding during a year.

constant dollars Dollars, or some other monetary unit, of constant purchasing power. In situations where inflationary or deflationary effects have been assumed when cash flows were estimated, those estimates are converted to constant dollars by adjustment by some readily accepted general inflation index. (See actual dollars and deflating.)

cost-benefit analysis See benefit-cost analysis.

cost effectiveness analysis An analysis in which the major benefits may not be expressed in monetary terms. One or more effectiveness measures are substituted for monetary values resulting in a trade off between marginal increases in effectiveness versus marginal increases in costs.

cost of capital A term, usually used in capital budgeting, to express as an interest rate percentage the overall cost of investment capital, including both equity and borrowed funds.

cutoff rate of return The rate of return after taxes that will be used as a criterion for approving projects or investments. It is determined by management based on the supply and demand for funds. It may or may not be equal to the minimum attractive rate of return.

decision theory With reference to engineering economy, it is a branch of economic analysis devoted to the study of decision processes involving multiple possible outcomes, defined either discretely or on a continuum, and deriving from the theory of games and economic behavior and probabilistic modeling.

decision tree In decision analysis, a graphical representation of the anatomy of a decision showing the interplay between a present decision, chance events, possible outcomes and future decisions, and their results or payoffs.

decisions under certainty In the literature of decision theory, that class of problems wherein single estimates with respect to cash flows and economic life (complete information) are used in arriving at a decision among alternatives.

decisions under risk In the literature of decision theory, that class of problems in which multiple outcomes are considered explicitly for each alternative and the probabilities of the outcomes are assumed to be known.

decisions under uncertainty In the literature of decision theory, that class of problems in which multiple outcomes are considered explicitly for each alternative but the probabilities of the outcomes are assumed to be unknown.

defender In replacement analysis, the presently owned property or equipment being considered for replacement by the most economical challenger. In the analysis of multiple alternatives, the previously judged acceptable alternative against which the next alternative to be evaluated (the challenger) is to be compared.

deflating (by a price index) Adjusting some nominal magnitude, e.g., an actual dollar estimate, by a price index in order to express that magnitude in units of constant purchasing power. (See actual dollars and constant dollars.)

deflation A decrease in the relative price level of a factor of production, an output, or the general price level of all goods and services. A deflationary period is one in which there is a sustained decrease in price levels.

demand factor (1) The ratio of the current production rate of the system divided by the maximum instantaneous production rate. (2) The ratio of the average production rate, as determined over a specified period of time, divided by the maximum production rate. (3) In electric utility operations, it is the ratio of the maximum kilowatt load demanded during a given period divided by the connected load. (Also see capacity factor and load factor.)

depletion (1) A lessening of the value of an asset due to a decrease in the quantity available for exploitation. It is similar to depreciation except that it refers to such natural resources such as coal, oil, and timber. (2) A form of capital recovery applicable to properties such as listed above. Its determination may be on a unit of production basis, related to original cost or appraised value of the resource (known as cost depletion), or based on a percentage of the income received from extracting or harvesting (known as percentage depletion).

depletion allowance An annual tax deduction based upon resource extraction. See depletion.

depreciation (1) a) Decline in value of a capitalized asset; b) A form of capital recovery, usually without interest, applicable to property with two or more years' life span in which an appropriate portion of the asset's value periodically is charged to current operations. (2) A loss of value due to physical or economic reasons. In accounting, depreciation is the allocation of this loss to current operations according to some systematic plan.

depreciation, accelerated Depreciation methods which write off the value (cost) of an asset usually over a shorter period of time (i.e., at a faster rate) than the expected economic life of the asset. For example, the Accelerated Cost Recovery System (ACRS) introduced in the U.S. in 1981.

depreciation allowance An annual tax deduction, and/or charge to current operations, of the original cost of a fixed asset. See depreciation.

depreciation basis In tax accounting, the cost or otherwise determined value of a group of fixed assets, including installation costs and certain other expenditures, and excluding certain allowances. The depreciation basis is the amount which by law may be written off for tax purposes over a period of years.

depreciation, declining balance A method of computing depreciation in which the annual charge is a fixed percentage of the depreciated book value at the beginning of the year to which the depreciation charge applies.

depreciation, multiple straight-line A method of depreciation accounting in which two or more straight-line rates are used. This method permits a predetermined portion of the asset to be written off in a fixed number of years. One common practice is to employ a straight-line rate which will write off 3/4 of the cost in the first half of the anticipated service life with a second straight-line rate used to write off the remaining 1/4 in the remaining half life.

depreciation, sinking fund A method of computing depreciation in which the periodic charge is assumed to be deposited in a sinking fund that earns interest at a specified rate. The sinking fund may be real but usually is hypothetical. (2) A method of depreciation where a fixed sum of money regularly is deposited at compound interest in a real or hypothetical fund in order to accumulate an amount equal to the total depreciation of an asset at the end of the asset's estimated life. The depreciation charge to operations for each period equals the sinking fund deposit amount plus interest on the beginning of period sinking fund balance.

depreciation, straight line A method of computing depreciation wherein the amount charged to current operations is spread uniformly over the estimated life of an asset. The allocation may be performed on a unit of time basis or a unit of production basis or some combination of the two.

depreciation, sum-of-years-digits A method of computing depreciation wherein the amount charged to current operations for any year is based on the ratio: (years of remaining life)/(1 + 2 + 3 + ... + n), n being the estimated life.

development cost The sum of all the costs incurred by an inventor or sponsor of a project up to the time that the project is accepted by those who will promote it.

direct cost A traceable cost that can be segregated and allocated against specific products, operations, or services.

discounted **cash flow** (1) Any method of handling cash flows over time, either receipts or disbursements, in which compound interest and compound interest formulae are employed in their analytical treatment. (2) An investment analysis which compares the present worth of projected receipts and disbursements occurring at designated times in order to estimate the rate of return from the investment or project. In this sense also see rate of return and profitability index.

earning value (earning power of money) The present worth of an income producer's estimated future net earnings as predicted on the basis of recent and present expenses and earnings and the business outlook.

economic life The period of time, extending from the date of installation to the date of retirement from the intended service, over which a prudent owner expects to retain an equipment or property so as to minimize cost or maximize net return.

economy (1) The cost or net return situation regarding a practical enterprise or project, as in economy study, engineering economy, or project economy. (2) A system for the management of resources. (3) The avoidance of (or freedom from) waste in the management of resources.

effective interest See interest, effective.

effectiveness Consequences of an investment not measured in monetary terms; e.g., reliability, maintainability, safety.

endowment A fund established for the support of some project or succession of donations or financial obligations.

endowment method As applied to an economy study, a comparison of alternatives based on the present worth or capitalized cost of the anticipated financial events.

engineering economy (1) The application of economic or mathematical analysis and synthesis to engineering decisions. (2) A body of knowledge and techniques concerned with the evaluation of the worth of commodities and services relative to their cost.

estimate A magnitude determined as closely as it can be by the use of past history and the exercise of sound judgment based upon approximate computations, not to be confused with offhand approximations that are little better than outright guesses.

exchange rate The rate at which the currency of one nation exchanges for that of another.

expected yield In finance, the ratio of the expected return from an investment divided by the investment.

external rate of return A rate of return calculation which takes into account the cash receipts and disbursements of a project and assumes that all net receipts (cash throwoffs) are reinvested elsewhere in the enterprise at some stipulated interest rate. (Also see rate of return and internal rate of return.)

fair rate of return The maximum rate of return which an investor owned public utility is entitled to earn on its rate base in order to pay interest and dividends and attract new capital. The rate, or percentage, usually is determined by state or federal regulatory bodies.

first cost The initial investment in a project or the initial cost of capitalized property including transportation, installation, preparation for service, and other related initial expenditures.

fixed cost Those costs which tend to be unaffected by changes in the number of units produced or the volume of service given.

future worth (1) The equivalent value at a designated future date based on the time value of money. (2) The monetary sum, at a given future time, which is equivalent to one or more sums at given earlier times when interest is compounded at a given rate.

going-concern value The difference between the value of a property as it stands possessed of its going elements and the value of the property alone as it would stand at completion of construction as a bare or inert assembly of physical parts.

good-will value That element of value which inheres in the fixed and favorable consideration of customers arising from an established well-known and well-conducted business. This is determined as the difference between what a prudent businessperson is willing to pay for the property and its going-concern value.

gradient factors A group of compound interest factors used for equivalence conversions of arithmetic or geometric gradients in cash flow. In general use are the arithmetic gradient to uniform series (gradient conversion) factor, the arithmetic gradient to present worth (gradient present worth) factor, and the geometric gradient to present worth factor.

increment cost (incremental cost) (1) The additional cost which will be incurred as the result of increasing the output by one unit more. Conversely, it may be defined as the cost which will not be incurred if the output is reduced by one unit. (2) The variation in output resulting from a unit change in input. (3) The difference in costs between a pair of mutually exclusive alternatives.

indirect cost Traceable or common costs which are not charged against specific products, operations, or services but rather are allocated against "all" products, operations, and/or services by a predetermined formula.

inflation A persistent rise in price levels, generally not justified by increased productivity, and usually resulting in a decline in purchasing power. Sometimes the term is used interchangeably with escalation. However this latter term more often is restricted to the differential increase in a price relative to general changes in price levels. (See deflation.)

intangibles (1) In economy studies, those elements, conditions or economic factors which cannot be evaluated readily or accurately in monetary terms. (2) In accounting, the assets of an enterprise which cannot reliably be values in monetary terms (e.g., goodwill). (See irreducibles.)

interest (1) The monetary return or other expectation which is necessary to divert money away from consumption and into long term investment. (2) The cost of the use of capital. It is synonymous with the term time value of money. (3) In accounting and finance, a) a financial share in a project or enterprise; b) periodic compensation for the lending of money.

interest rate The ratio of the interest accrued in a given period of time to the amount owed or invested at the start of that period.

interest rate, effective The actual interest rate for one specified period of time. Frequently the term is used to differentiate between nominal annual interest rates and actual annual interest rates when there is more than one compounding period in a year.

interest rate, nominal (1) The interest rate for some period of time which ignores the compounding effect of interest calculations during subperiods within that period. (2) The annual interest rate, or Annual Percentage Rate (APR), frequently quoted in the media.

internal rate of return A rate of return calculation which takes into account only the cash receipts and disbursements generated by an investment. (Also see rate of return and external rate of return.)

investment (1) As applied to an enterprise as a whole, the cost (or present value) of all the properties and funds necessary to establish and maintain the enterprise as a going concern. The capital tied up in an enterprise or project. (2) Any expenditure which has substantial and enduring value (generally more than one year) and which is therefore capitalized.

investor's method A term most often used in the valuation of bonds. See rate of return and discounted cash flow.

irreducibles Those intangible conditions or economic factors which cannot readily be reduced to monetary terms (e.g., ethical considerations or esthetic values).

leaseback A business arrangement wherein the owner of land, buildings, and/or equipment sells such assets and simultaneously leases them back under a long term lease.

life (1) **economic:** that period of time after which a machine or facility should be retired from primary service and/or replaced as determined by an engineering economy study. The economic impairment may be absolute or relative. (2) **physical:** that period of time after which a machine or facility can no longer be repaired or refurbished to a level such that it can perform a useful function. (3) **service:** that period of time after which a machine or facility cannot perform satisfactorily its intended function without major overhaul.

load factor (1) Applied to physical plant or equipment, it is the ratio of average load for some period of time to maximum load. Frequently it is expressed as a percentage. (2) In electric utility operations, it is the average load for some period of time divided by the maximum load. (Also see **capacity factor** and **demand factor**.)

MAPI method A procedure for equipment replacement analysis developed by George Terborgh for the Machinery and Allied Products Institute. It uses a fixed format and provides charts and graphs to facilitate calculations. A prominent feature of this method is that it includes explicitly an allowance for obsolescence.

marginal cost (1) The rate of change of cost as a function of production or output. (2) The cost of one additional unit of production, activity, or service. (See incremental cost.)

Matheson formula A title for the formula used for declining balance depreciation. (See declining balance depreciation.)

maximax criterion In decision theory, probabilities unknown, a rule that says choose the alternative with the maximum of the maximum returns identified for each alternative.

maximin criterion In decision theory, probabilities unknown, a rule that says choose the alternative with the maximum of the minimum returns identified for each alternative. Also called a maximum security level strategy or Wald's strategy.

minimax criterion In decision theory, probabilities unknown, a rule that says choose the alternative with the minimum of the maximum costs identified for each alternative. Also called a maximum security level strategy.

minimin criterion In decision theory, probabilities unknown, a rule that says choose the alternative with the minimum of the minimum costs identified for each alternative.

minimax regret criterion In decision making under uncertainty, a rule that says choose the alternative with the least potential net return or cost regret.

minimum attractive rate of return The effective annual rate of return on investment, either before or after taxes, which just meets the investor's threshold of acceptability. Sometimes termed the minimum acceptable return.

minimum cost life See economic life.

multiple rates of return (multiple roots) A situation in which the structure of a cash flow time series is such that it contains more than one solving internal rate of return.

nominal interest See interest rate, nominal.

obsolescence (1) The condition of being out-of-date. A loss of value occasioned by new developments which place the older property at a competitive disadvantage. A factor in depreciation. (2) A decrease in the value of an asset brought about by the development of new and more economical methods, processes, and/or machinery. (3) The loss of usefulness or worth of a product or facility as the result of the appearance of better and/or more economical products, methods, or facilities.

opportunity cost The cost of not being able to invest in an alternative, due to limited resources being applied to another "approved" alternative, and thus not being available for investment in other income-producing alternatives. Sometimes expressed as a rate.

payback period (1) Regarding an investment, the number of years (or months) required for the related profit or savings in operating cost to equal the amount of said investment. (2) The period of time at which a machine, facility, or other investment has produced sufficient net revenue to recover its investment costs.

payback period, discounted Same as payback period except the period includes a return at the interest rate used in the discounting.

payoff period See payback period.

payoff table A tabular presentation of the payoff results of complex decision questions involving many alternatives, events, and possible future states.

payout period See payback period.

perpetual endowment An endowment with hypothetically infinite life. (See capitalized cost and endowment.)

planning horizon (1) A stipulated period of time over which proposed projects are to be evaluated. (2) That point of time in the future at which subsequent courses of action are independent of decisions made prior to that time. (3) In utility theory, the largest single dollar amount that a decision maker would recommend be spent. (Also see utility.)

present worth (1) The monetary sum which is equivalent to a future sum or sums when interest is compounded at a given rate. (2) The discounted value of future sums.

present worth factor (1) Mathematical formulae involving compound interest used to calculate present worths of various cash flow streams. In table form, these formulae may include factors to calculate the present worth of a single payment, of a uniform annual series, of an arithmetic gradient, and of a geometric gradient. (2) A mathematical expression also known as the present value of an annuity of one. (The present worth factor, uniform series, also is known as the annuity fund factor.)

principal Property or capital, as opposed to interest or income.

profitablility index An economic measure of project performance. There are a number of such indexes described in the literature. One of the most widely quoted is one originally developed and so named (the PI) by Ray I. Reul, which essentially is based upon the internal rate of return. (Also see discounted cash flow, investor's method and rate of return.)

promotion cost The sum of all expenses found to be necessary to arrange for the financing and organizing of the business unit which will build and operate a project.

rate of return (internal rate of return) (1) The interest rate earned by an investment. (2) The interest rate at which the present worth equation (or the equivalent annual worth or future worth equations) for the cash flows of a project or project increment equals zero.

rate of return, external A rate of return calculation which employs one or more supplemental interest rates to produce equivalence transformations on a portion or all of the cash flows and then solves for rate of return on that equivalent cash flow series.

replacement policy A set of decision rules for the replacement of facilities that wear out, deteriorate, or fail over a period of time. Replacement models generally are concerned with comparing the increasing operating costs (and possibly decreasing revenues) associated with aging equipment against the net proceeds from alternative equipment.

replacement study An economic analysis involving the comparison of an existing facility and one or more facilities proposed to supplant or displace the existing facility.

required return The minimum return or profit necessary to justify an investment. Often it is termed interest, expected return or profit, or charge for the use of capital. It is the minimum acceptable percentage, no more and no less.

retirement of debt The termination of a debt obligation by appropriate settlement with the lender. The repayment is understood to be in full amount unless partial settlement is specified.

risk (1) Exposure to a chance of loss or injury. (2) Exposure to undesired economic consequences.

risk analysis Any analysis performed to assess economic risk. Often this term is associated with the use of decision trees.

salvage value (1) The cost recovered or which could be recovered from a used property when removed from service, sold, or scrapped. A factor in appraisal of property value and in computing depreciation. (2) Normally, an estimate of an asset's net market value at the end of its estimated life. In some cases, the cost of removal may exceed any sale or scrap value; thus net salvage value is negative. (3) The market value of a machine or facility at any point in time.

sensitivity The relative magnitude of decision criterion change with changes in one or more elements of an economy study. If the relative magnitude of the criterion exhibits large change, the criterion is said to be sensitive; otherwise it is insensitive.

sensitivity analysis A study in which the elements of an engineering economy study are changed in order to test for sensitivity of the decision criterion. Typically it is used to assess needed measurement or estimation precision and often it is used as a substitute for more formal methods such as risk analysis.

service life See life.

simple interest (1) Interest that is not compounded, i.e., is not added to the income-producing investment or loan. (2) Interest charges under the condition that interest in any time period is only charged on the principal. Frequently interest is charged on the original principal amount disregarding the fact that the principal still owing may be declining through time. (Also see interest rate, nominal.)

sinking fund (1) A fund accumulated by periodic deposits and reserved exclusively for a specific purpose, such as retirement of a debt or replacement of a property. (2) A fund created by making periodic deposits (usually equal) at compound interest in order to accumulate a given sum at a given future time usually for some specific purpose.

sinking fund deposit factor See sinking fund factor.

sinking fund factor The function of interest rate and time that determines the periodic deposit required to accumulate a specified future amount.

study period The length of time that is presumed to be covered in the schedule of events and appraisal of results. Often it is the anticipated life of the project under consideration, but may be either longer or (more likely) shorter. (Also see life and planning horizon.)

sunk cost A cost which, since it occurred in the past, has no relevance with respect to estimates of future receipts or disbursements. This concept implies that, since a past outlay is the same regardless of the alternative selected, it should not influence the choice among alternatives.

time value of money (1) The cumulative effect of elapsed time and the money value of an event, based on the earning power of equivalent invested funds and on changes in purchasing power. (2) The expected interest rate that capital should or will earn. (See interest.)

traceable costs Cost elements which can be identified witn a given product, operation, or service.

uncertainty (1) That which is indeterminate, indefinite, or problematical. (2) An attribute of the precision of an individual's or group's precision of knowledge about some fact, event, consequence, or measurement.

uniform gradient series A uniform or arithmetic pattern of receipts or disbursements increasing or decreasing by a constant amount in each time period. (See gradient factor.)

utility (1) In economics, a process of evaluating factor inputs and outputs in quantitative units (Utiles) in order to arrive at a single measure of performance to assist in decision making. (2) A measured preference among various choices available in risk situations based on the decision making environment, the alternatives being considered, and the decision makers personal attitudes.

utility function A mathematically derived relationship between utility, measured in utiles, and quantities of money and/or commodities or attributes based on a decision maker's attitudes and preferences.

valuation or appraisal The art and science of estimating the fair exchange monetary value of specific properties.

variable cost A cost which tends to fluctuate according to changes in the number of units produced. (Also see marginal cost.)

working capital (1) That portion of investment represented by current assets (assets that are not capitalized) less the current liabilities. The capital necessary to sustain operations. (2) Those funds required to make the enterprise or project a going concern.

yield In bond valuation, the annual dividend of a bond divided by the current market price and usually expressed as a percent.